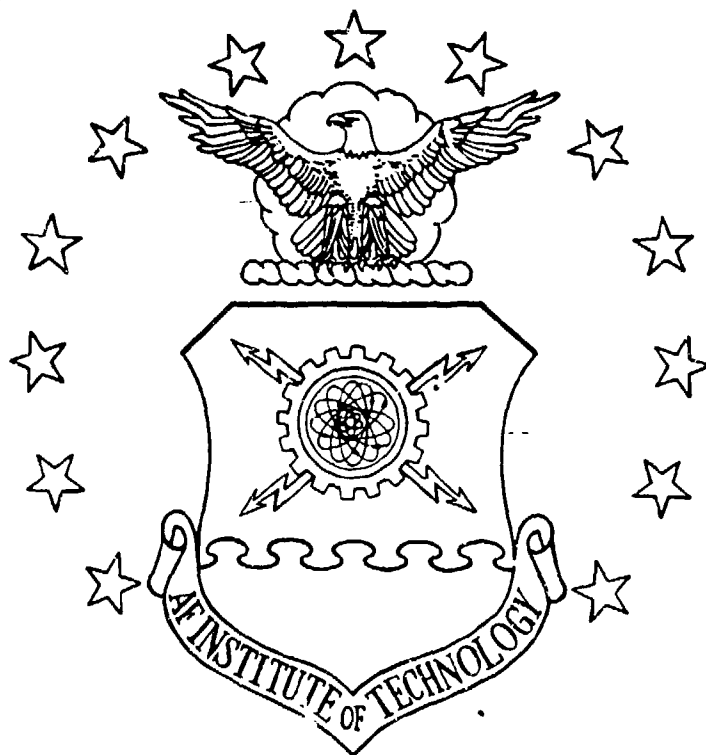


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THE APPLICATION OF KRIGING  
IN THE STATISTICAL ANALYSIS  
OF ANTHROPOMETRIC DATA  
VOLUME II

THESIS

Michael Grant  
Captain, USAF

AFIT/GOR/ENY/ENS/90M-8

DEPARTMENT OF THE AIR FORCE  
AIR UNIVERSITY

**AIR FORCE INSTITUTE OF TECHNOLOGY**

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Quality flight equipment is essential to flight crew safety and performance. Oxygen masks, night-vision goggles, and other apparatus must fit crew members comfortably and with complete functional precision. A problem currently facing the Air Force is the inconsistent quality of flight equipment. As new equipment is developed to improve crew members' performance, the requirement for design engineers to accurately account for the shape and variability of facial features becomes more critical.

This thesis develops the application of kriging in the statistical analysis of anthropometric data to support improvements in the design of flight equipment. Specifically, the geostatistical estimation technique of kriging is used to estimate the facial surfaces which influence the designs of flight apparatus. These surfaces account for the shape of the facial features and minimize the variance between individuals. A Kalman filter is developed to update and aggregate the kriged surfaces. As a proof of concept study, the techniques are demonstrated using data to support the design of the night-vision goggles currently under development. To further enhance the surface estimates, a multivariate analysis is performed to identify the factors which account for the majority of the variability between faces and to group the faces into homogenous clusters.

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THE APPLICATION OF KRIGING IN THE STATISTICAL  
ANALYSIS OF ANTHROPOMETRIC DATA  
VOLUME II

THESIS

Presented to the Faculty of the School of Engineering  
of the Air Force Institute of Technology  
Air University  
In Partial Fulfillment of the  
Requirements for the Degree of  
Master of Science in Operations Research

Michael Grant, B.S., M.S.  
Captain, USAF

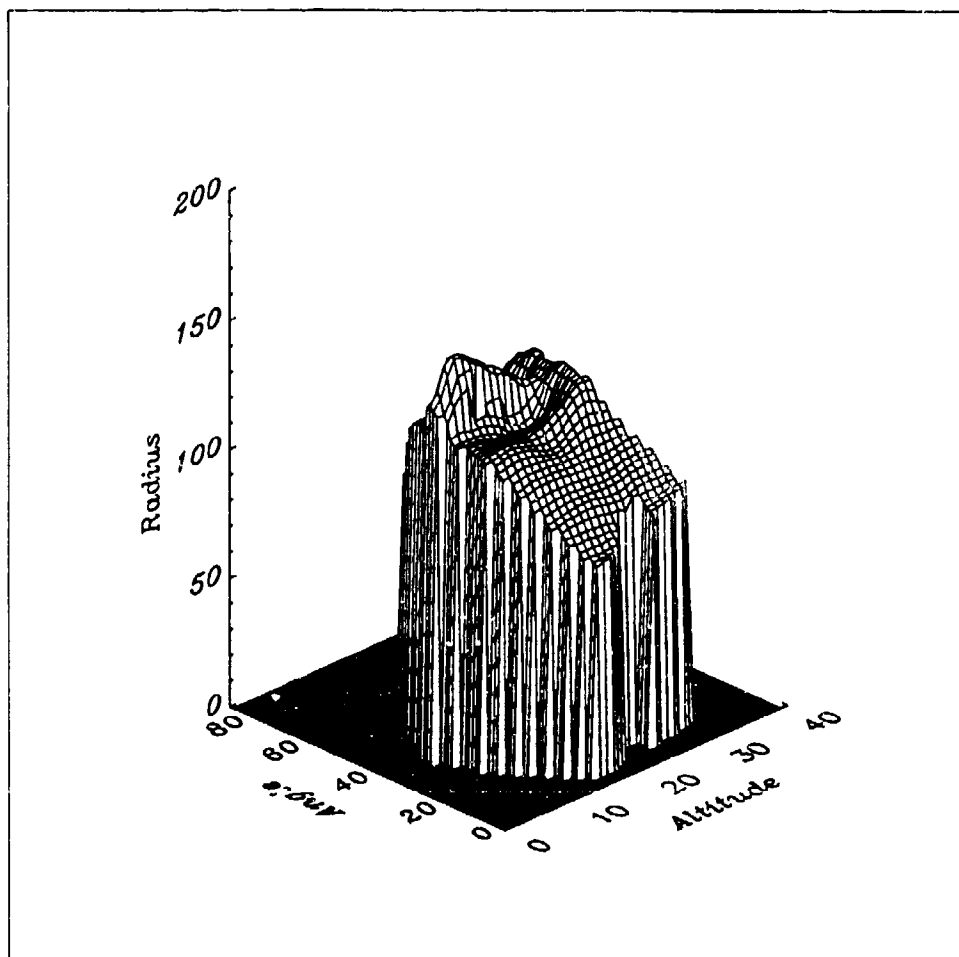
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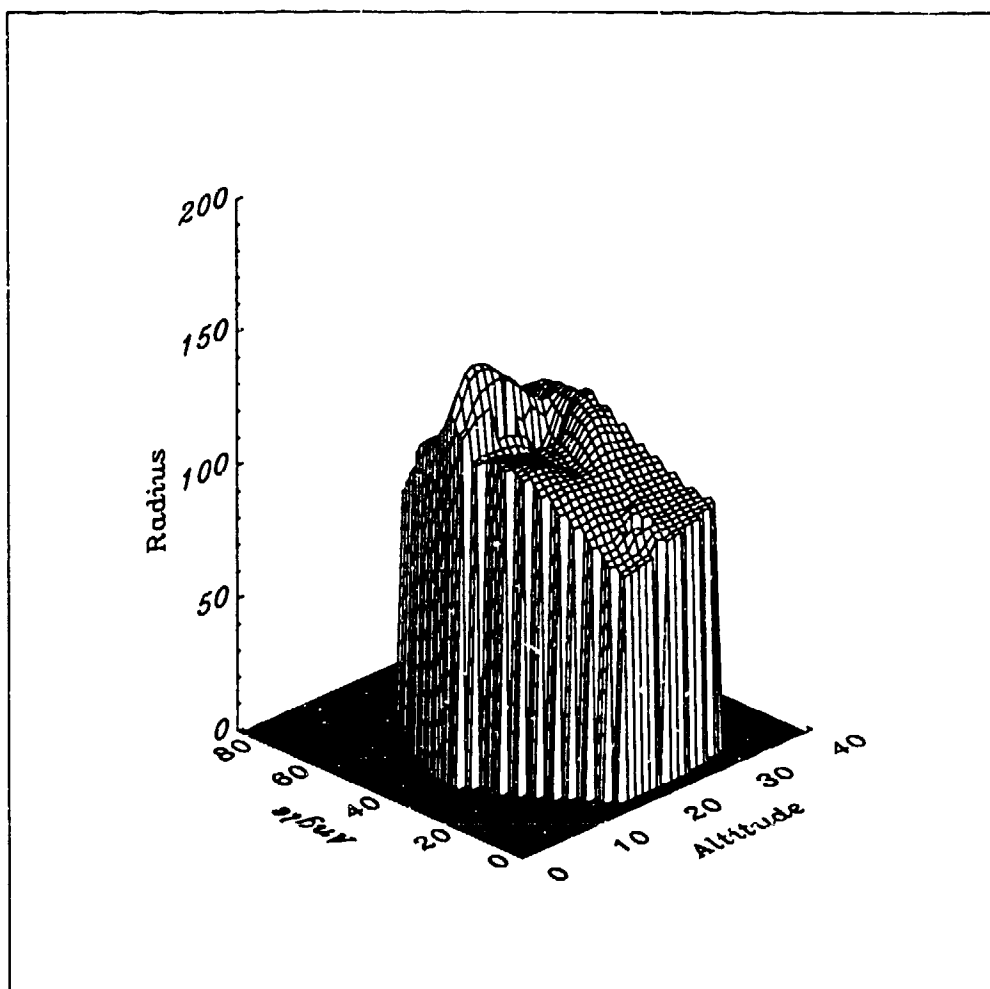
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## Appendix A. *Subjects*

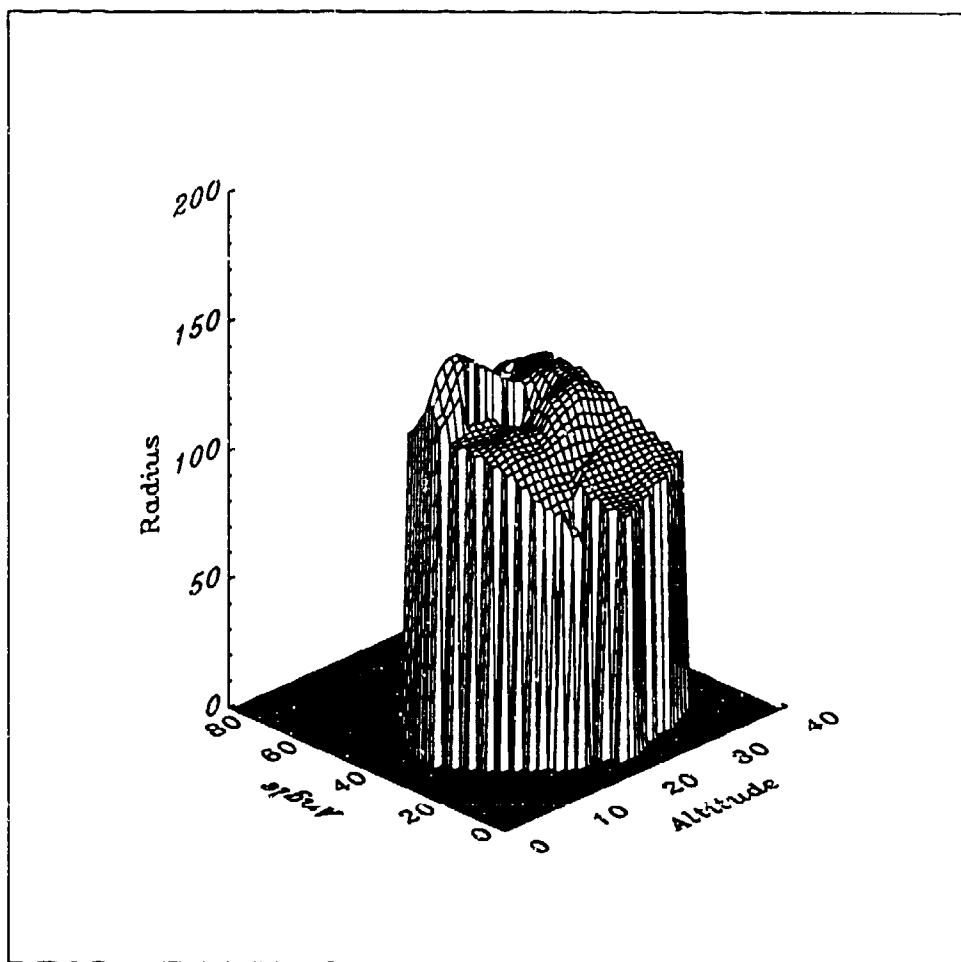
This appendix provides a graphical representation of the facial data used for this research effort. The first 25 subjects were included in the trend analysis and the final variogram analysis. The next five subjects were used in the kriging and updating analysis. Following these subjects are a group of five faces which were used only in the trend analysis. The last two faces were considered for the analysis but discarded because of inherent shortfalls in the data.



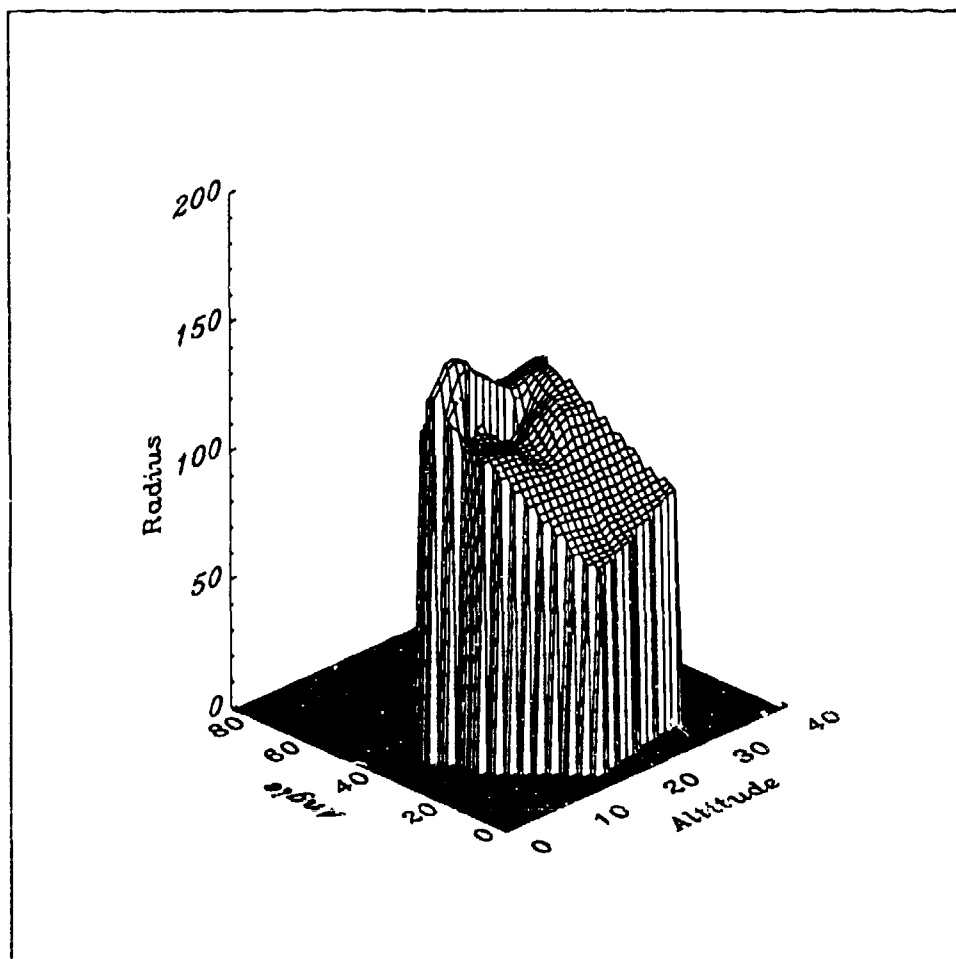
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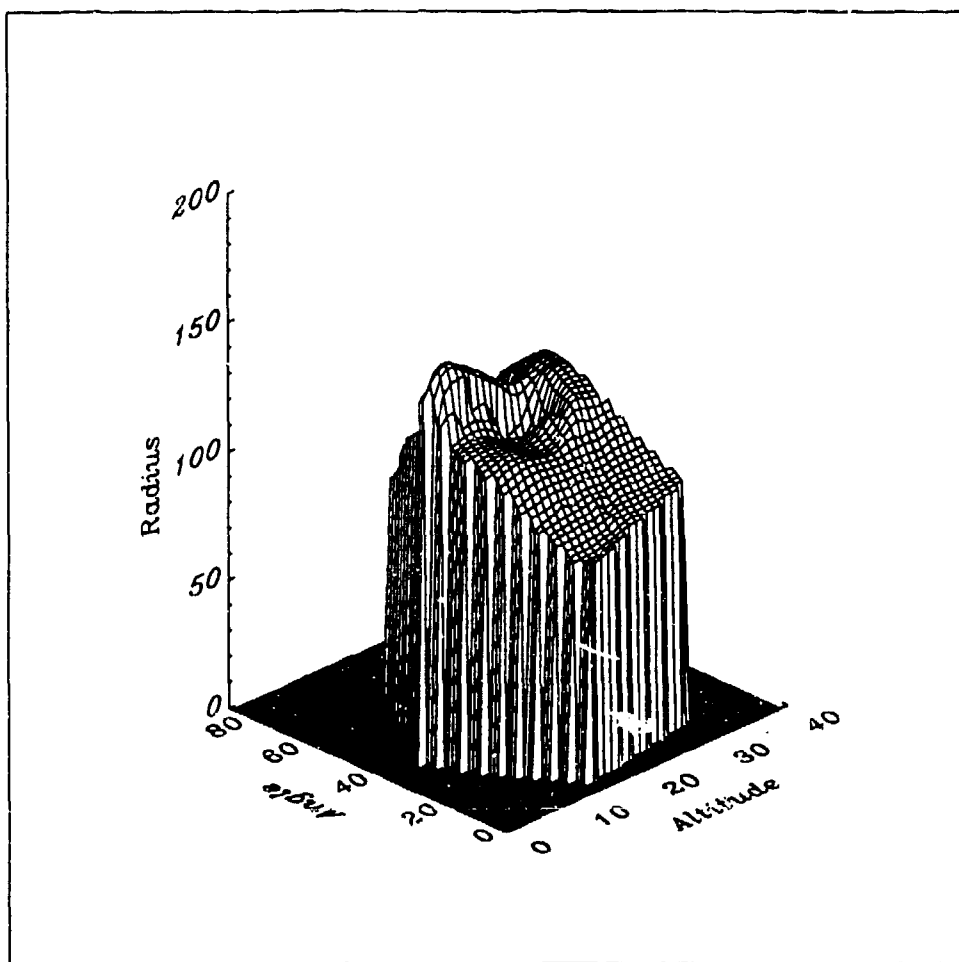
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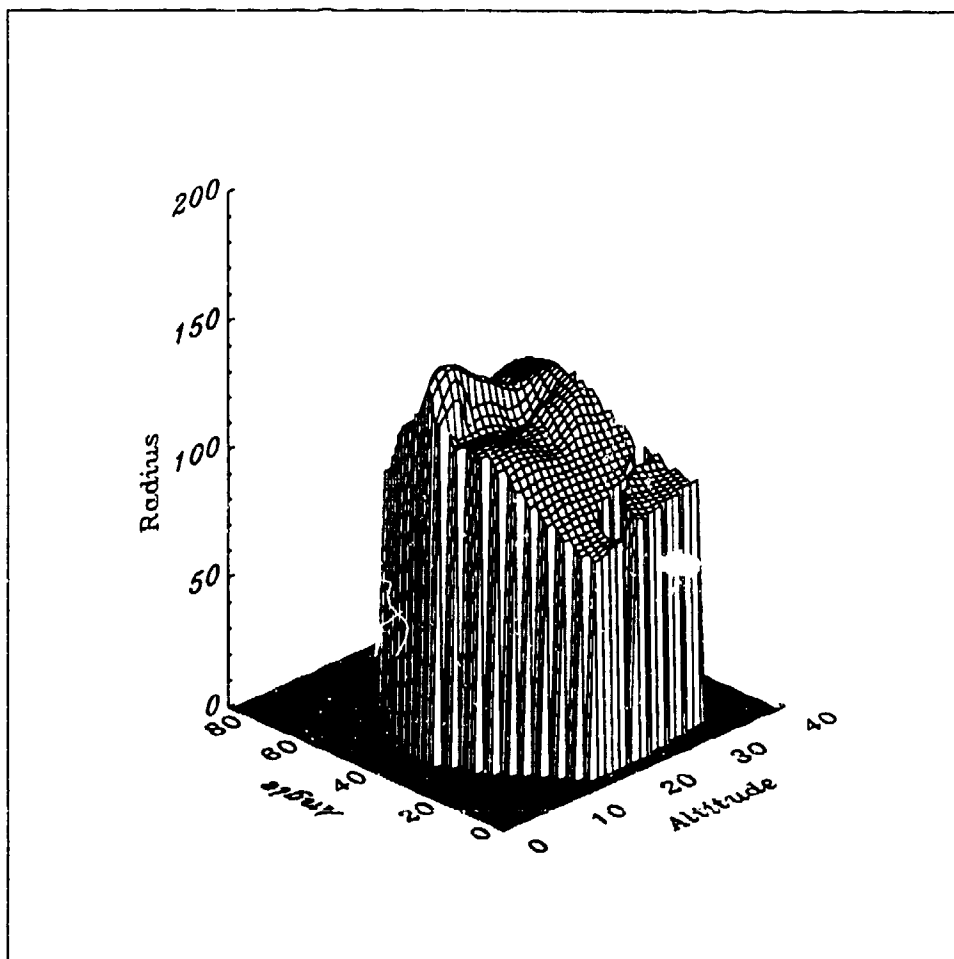
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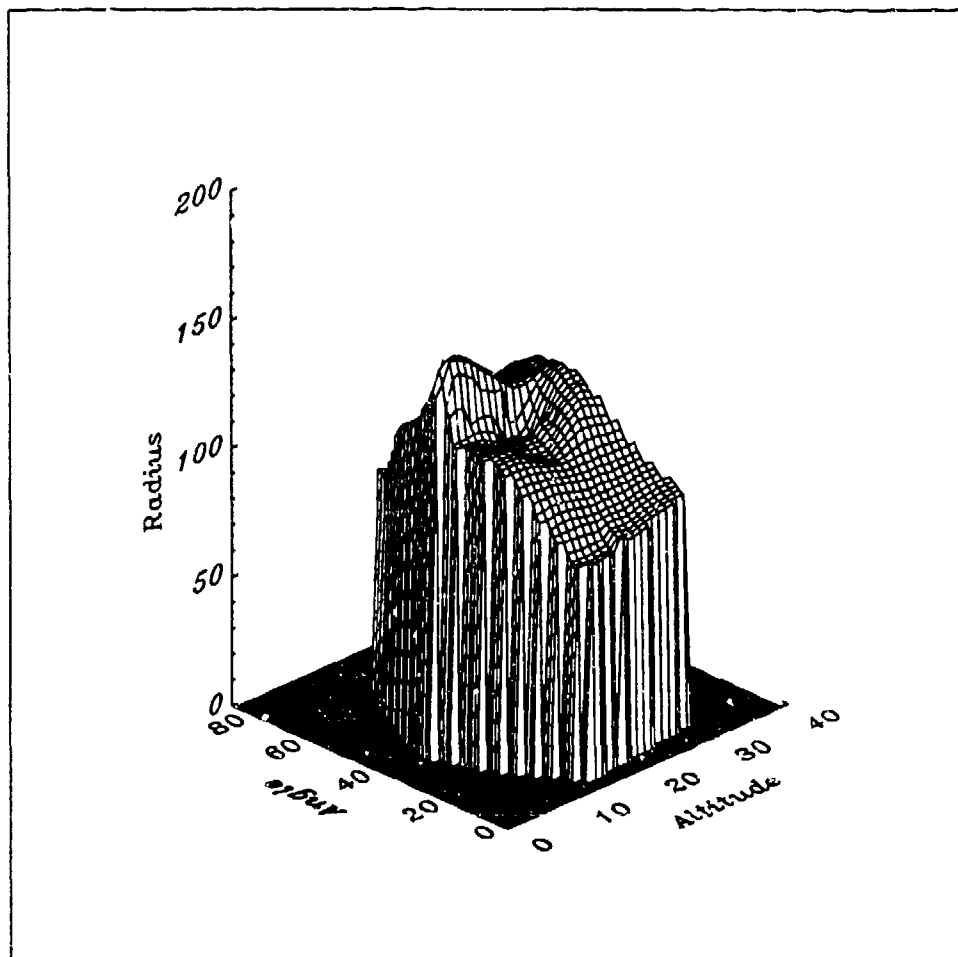
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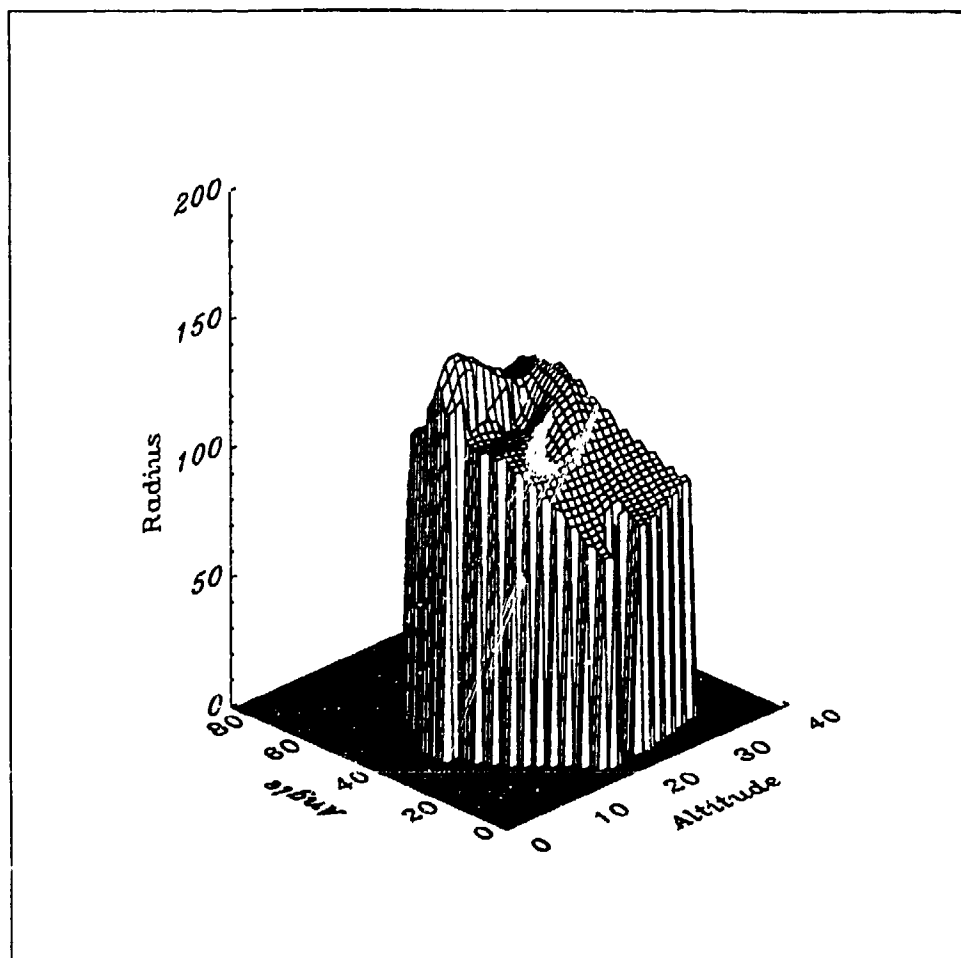
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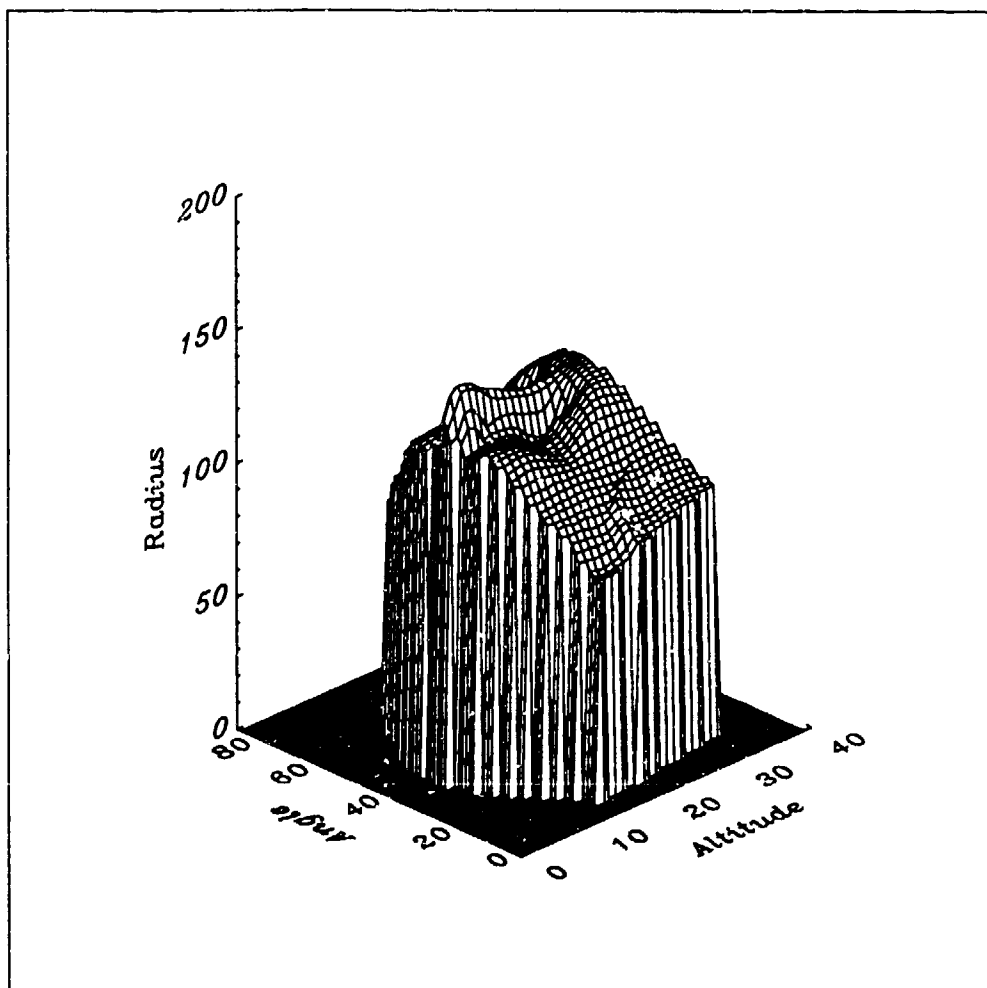
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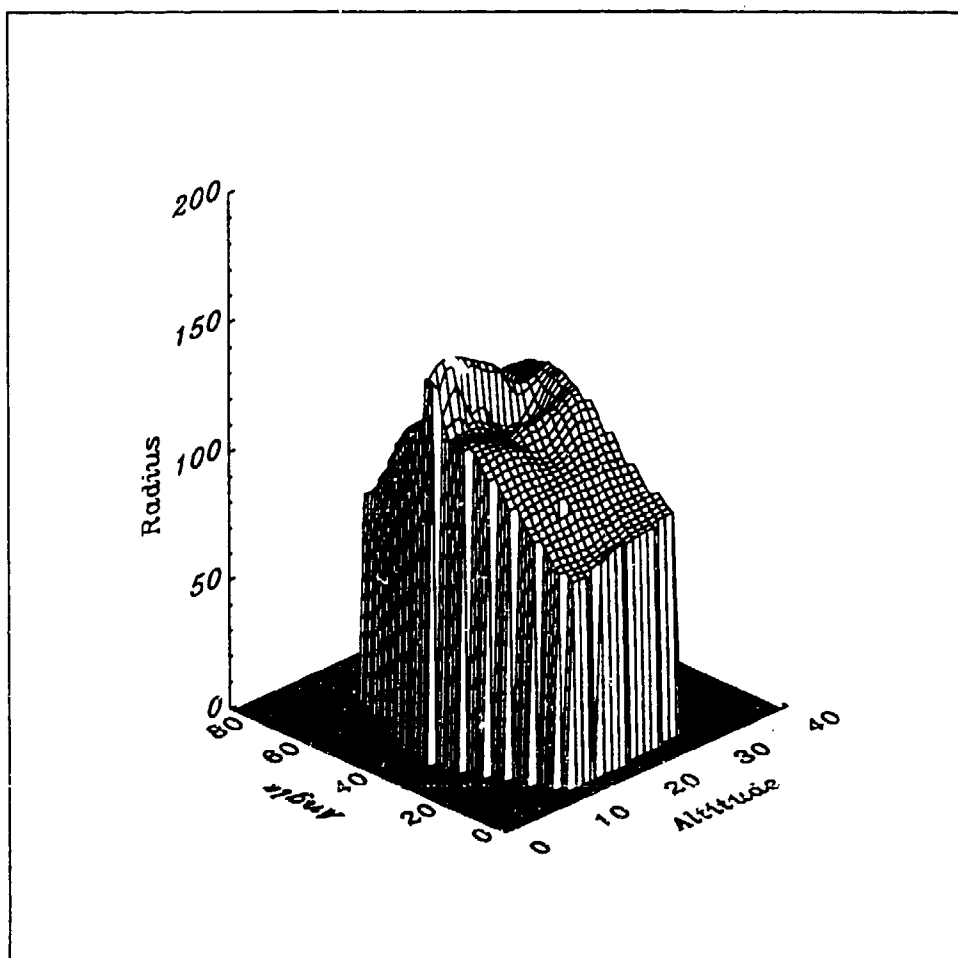
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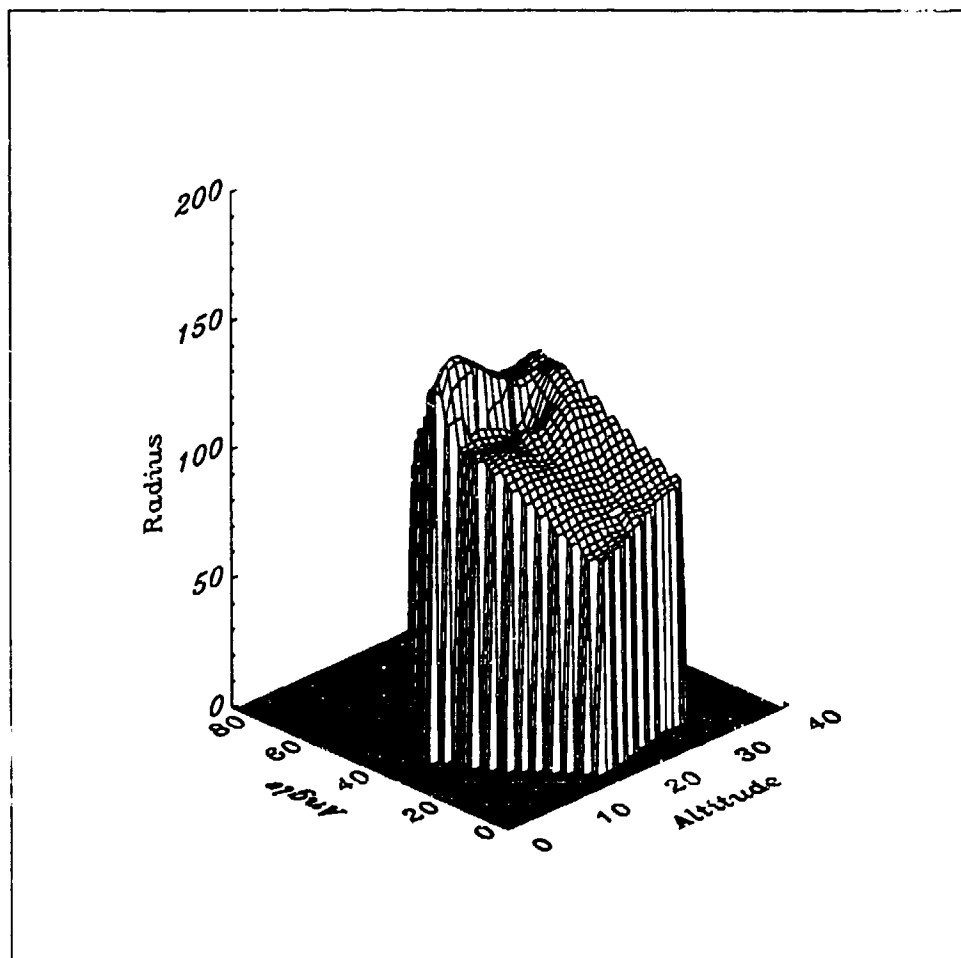
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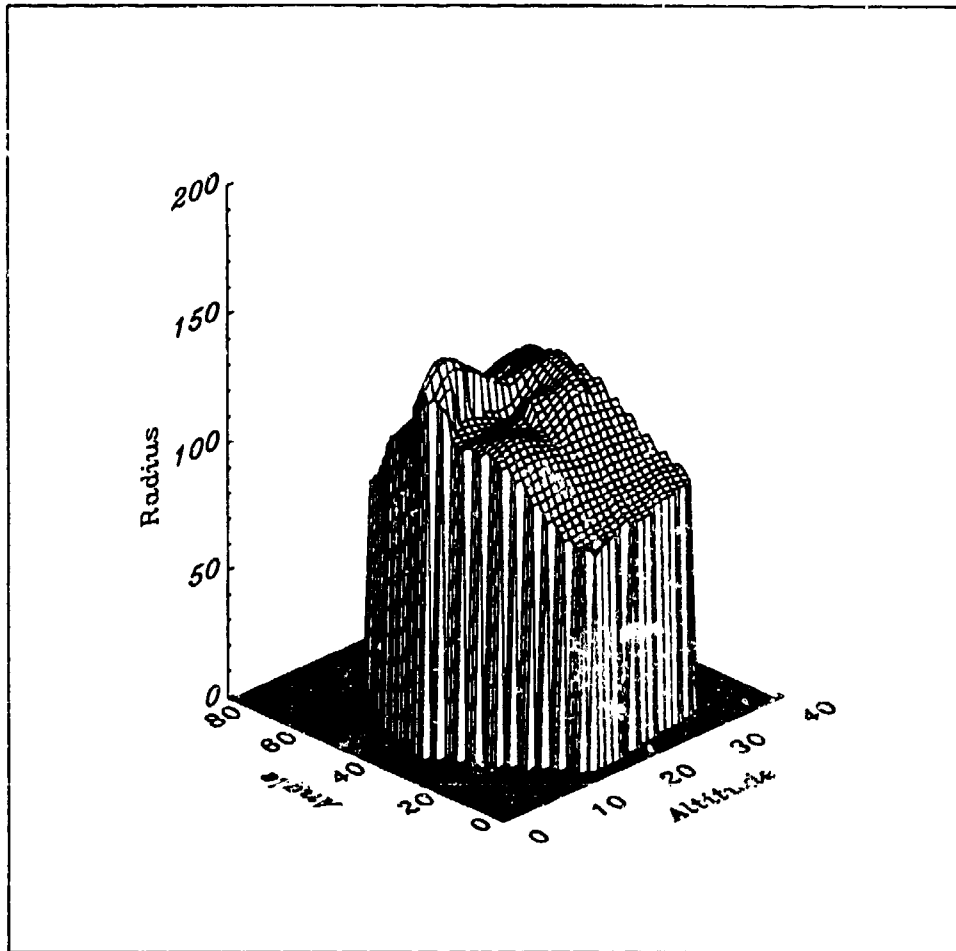
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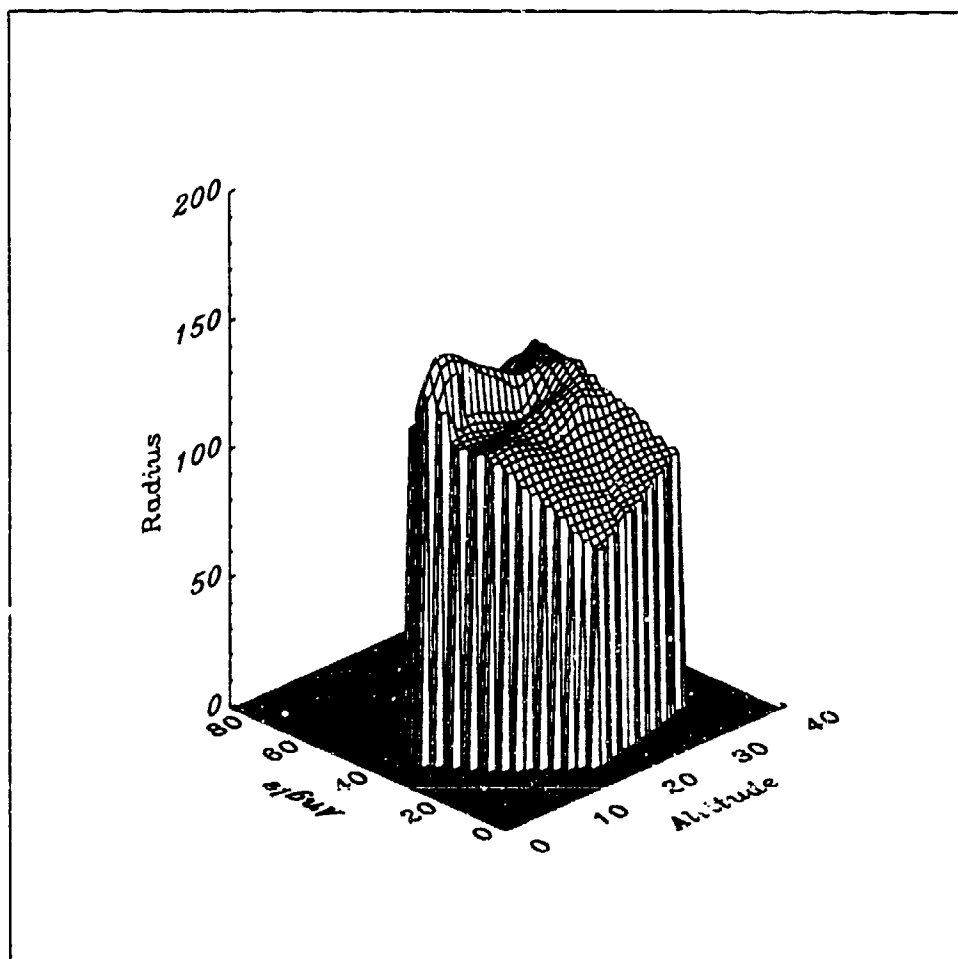
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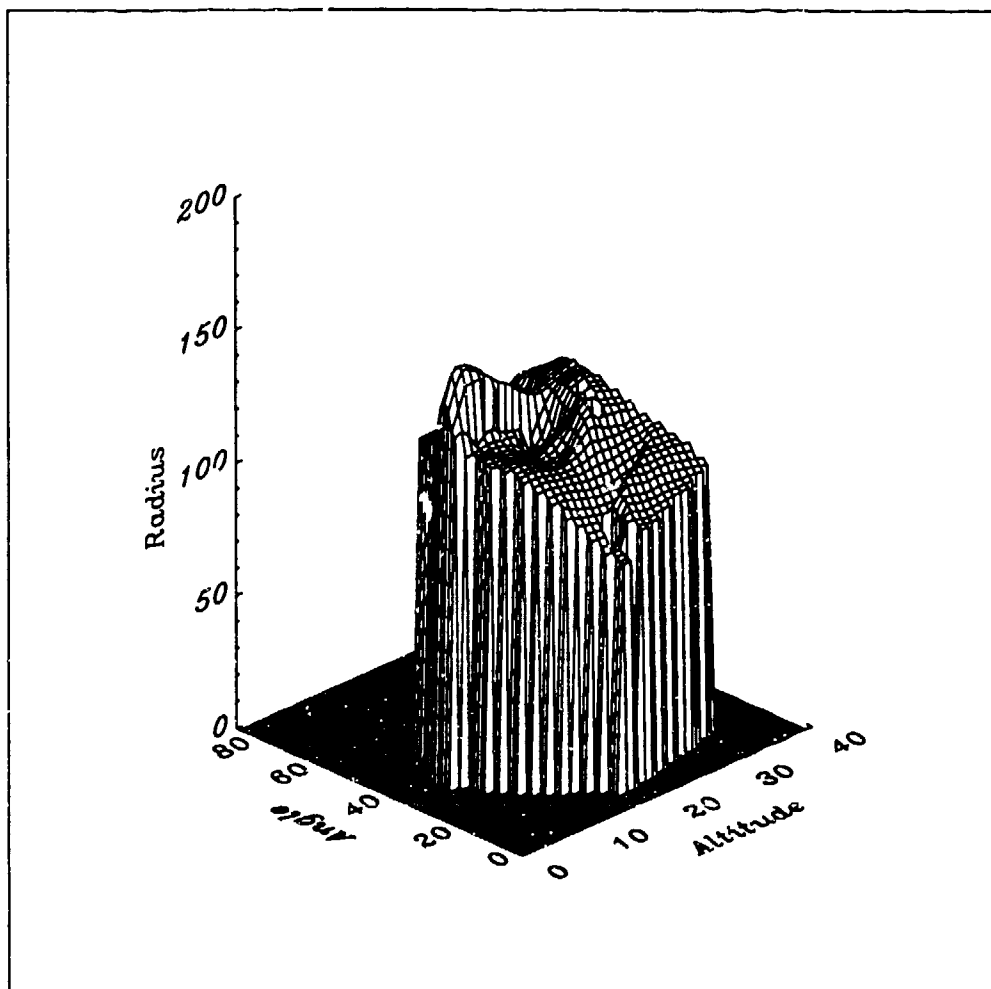
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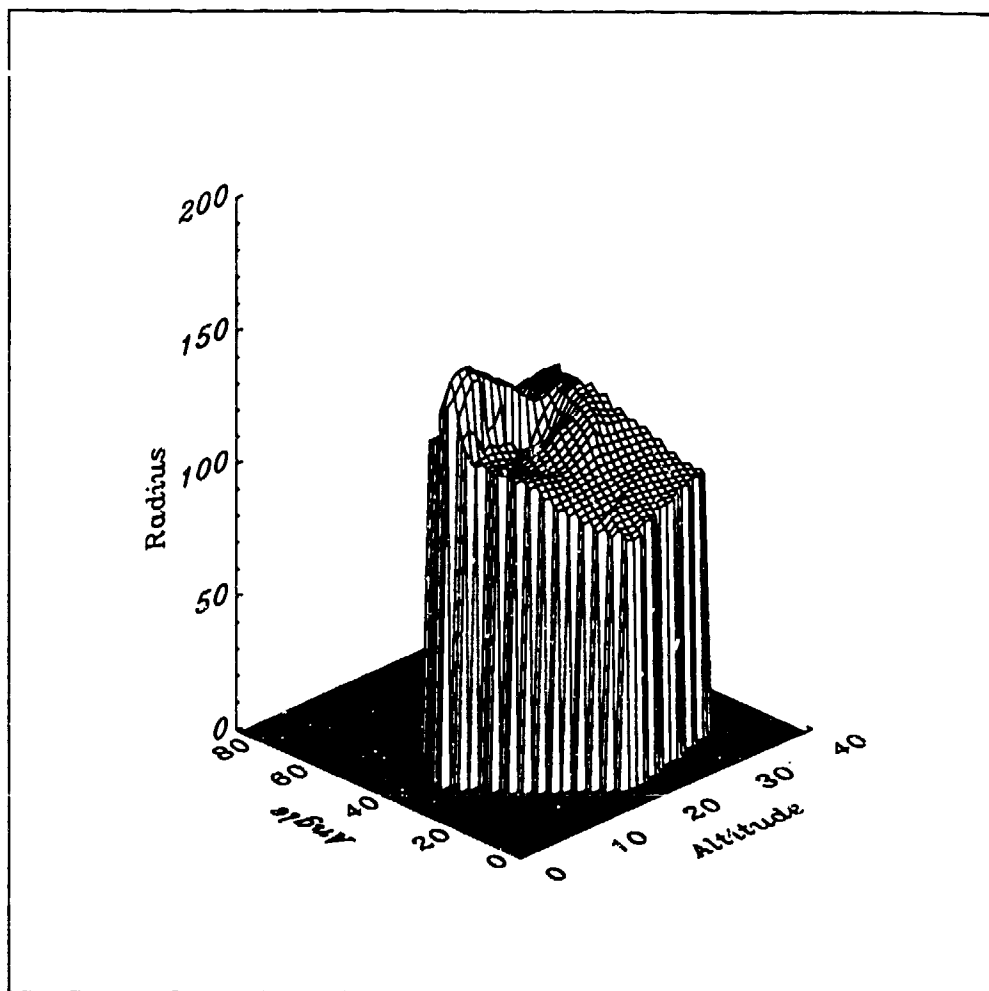
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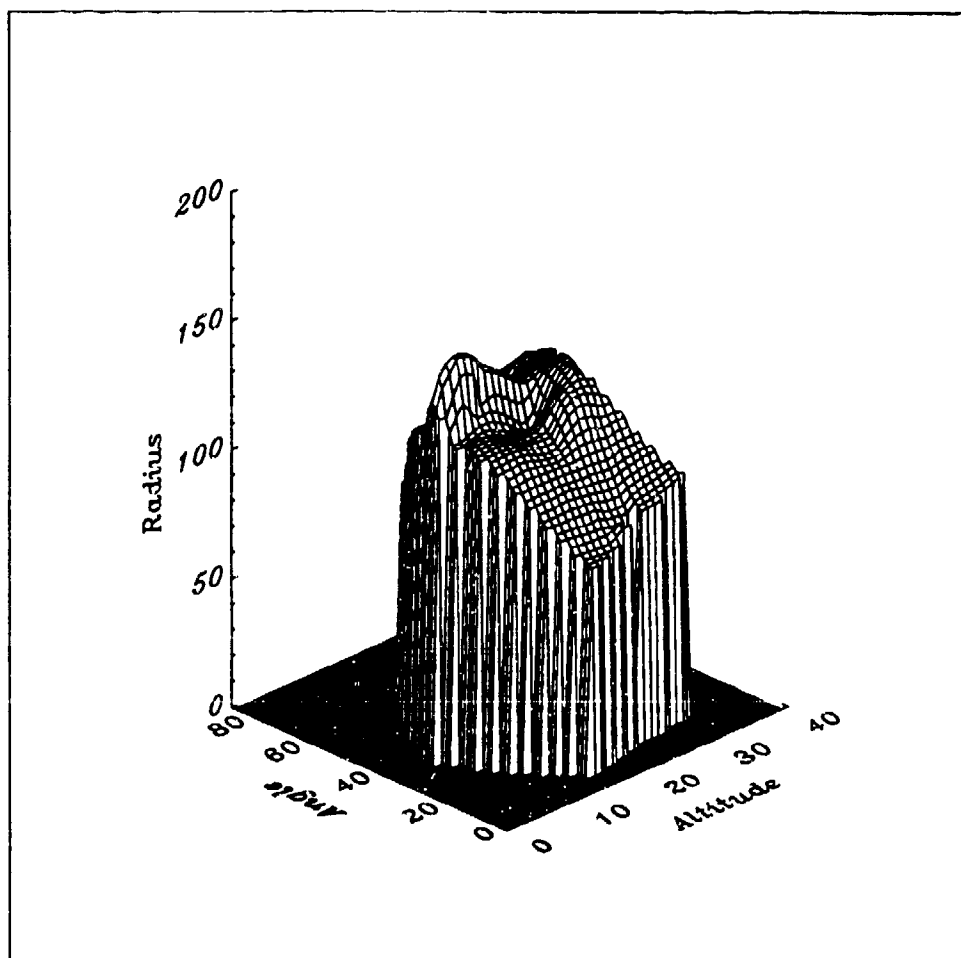
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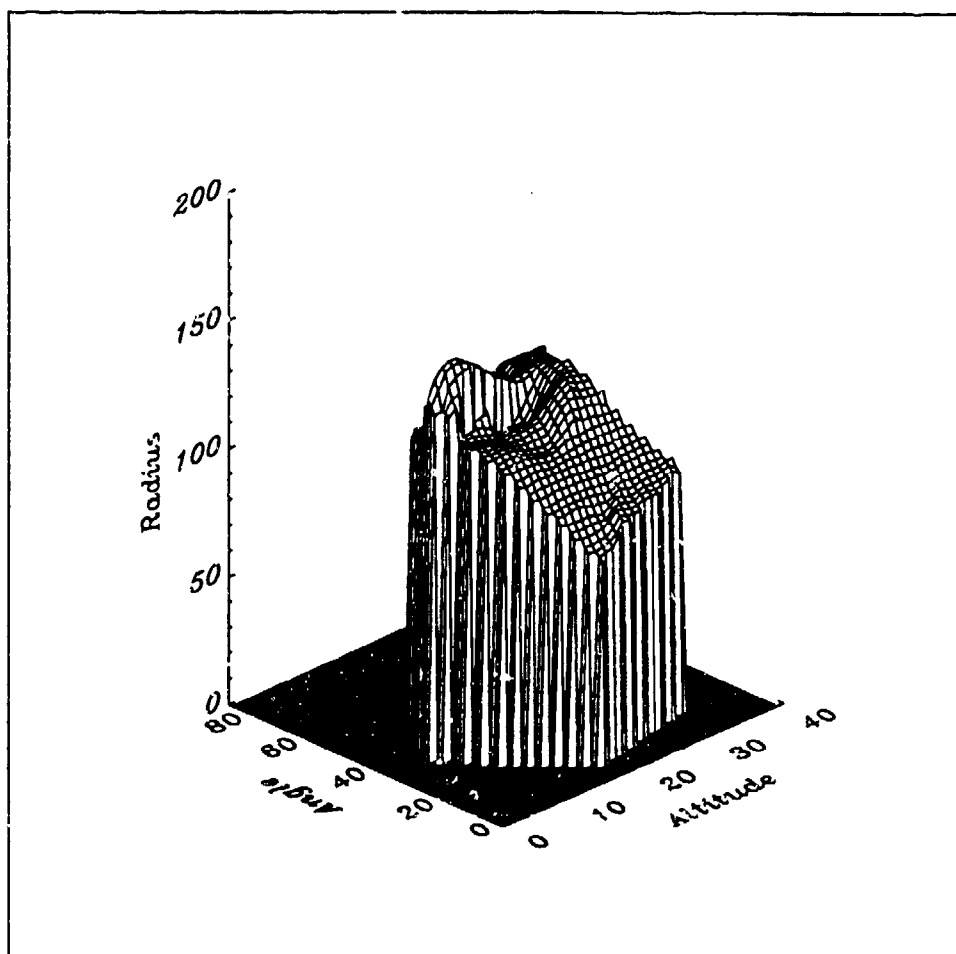
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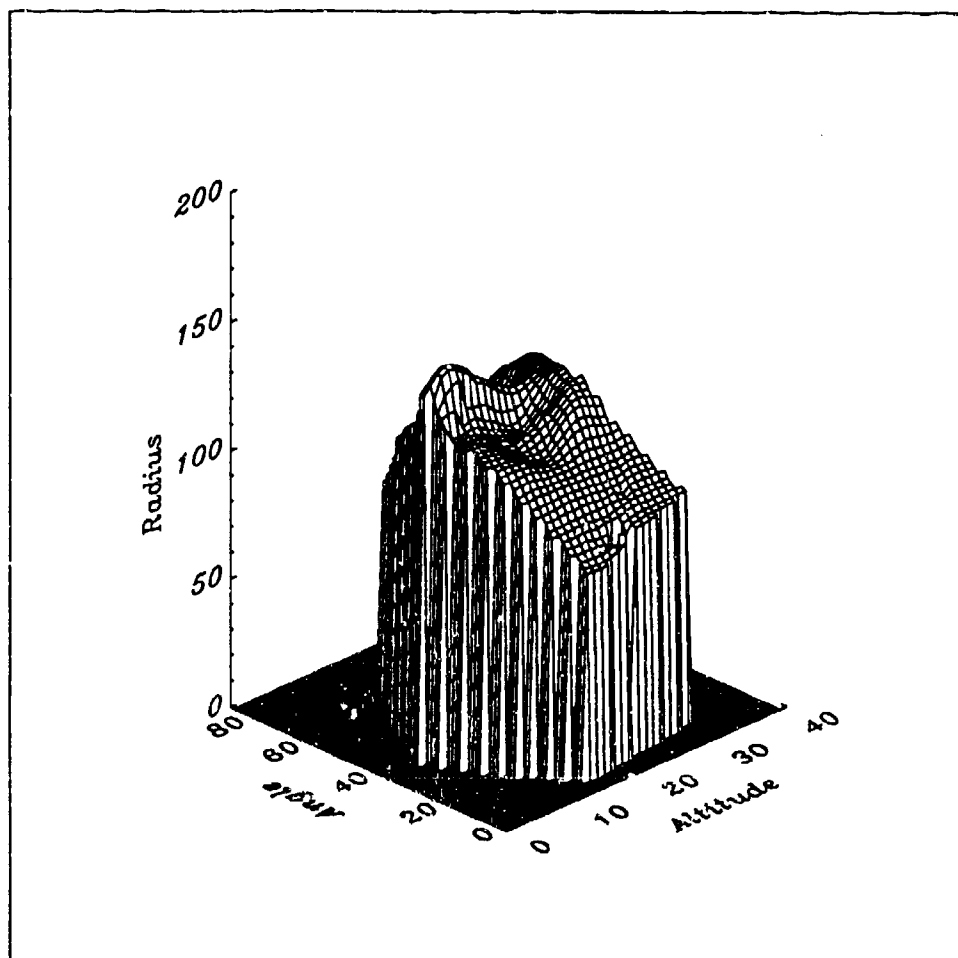
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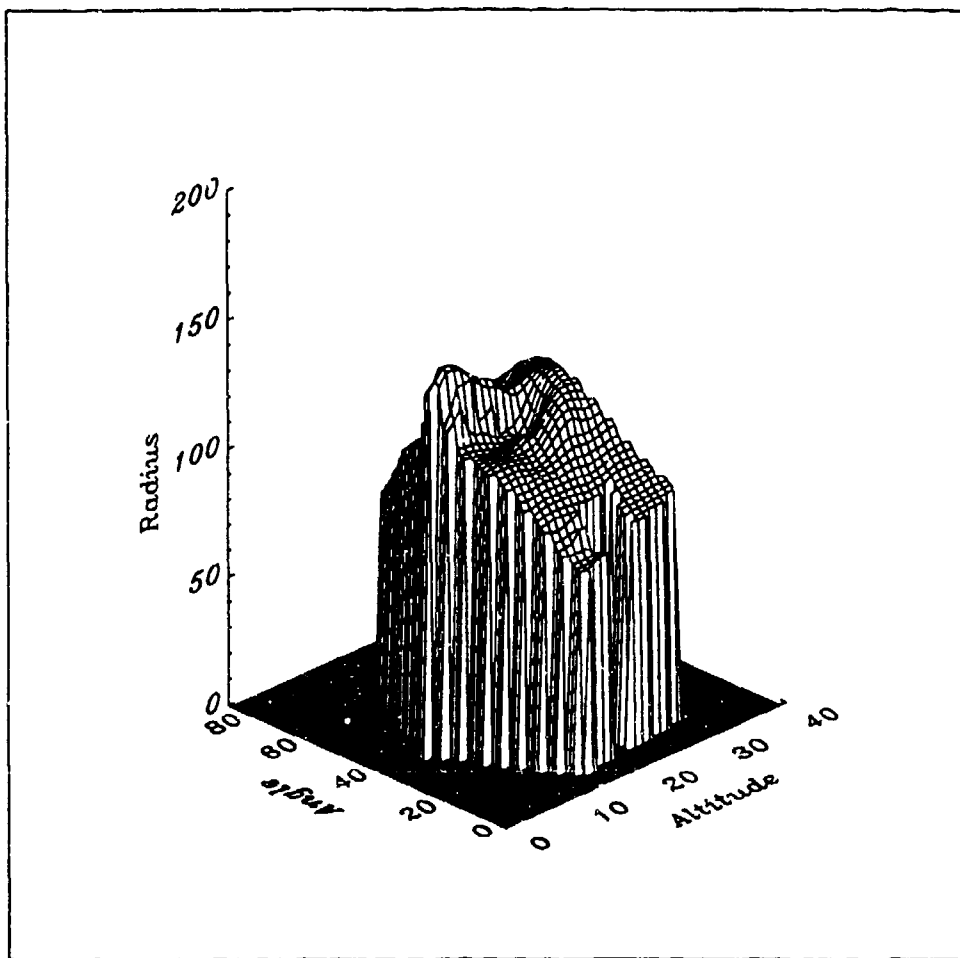
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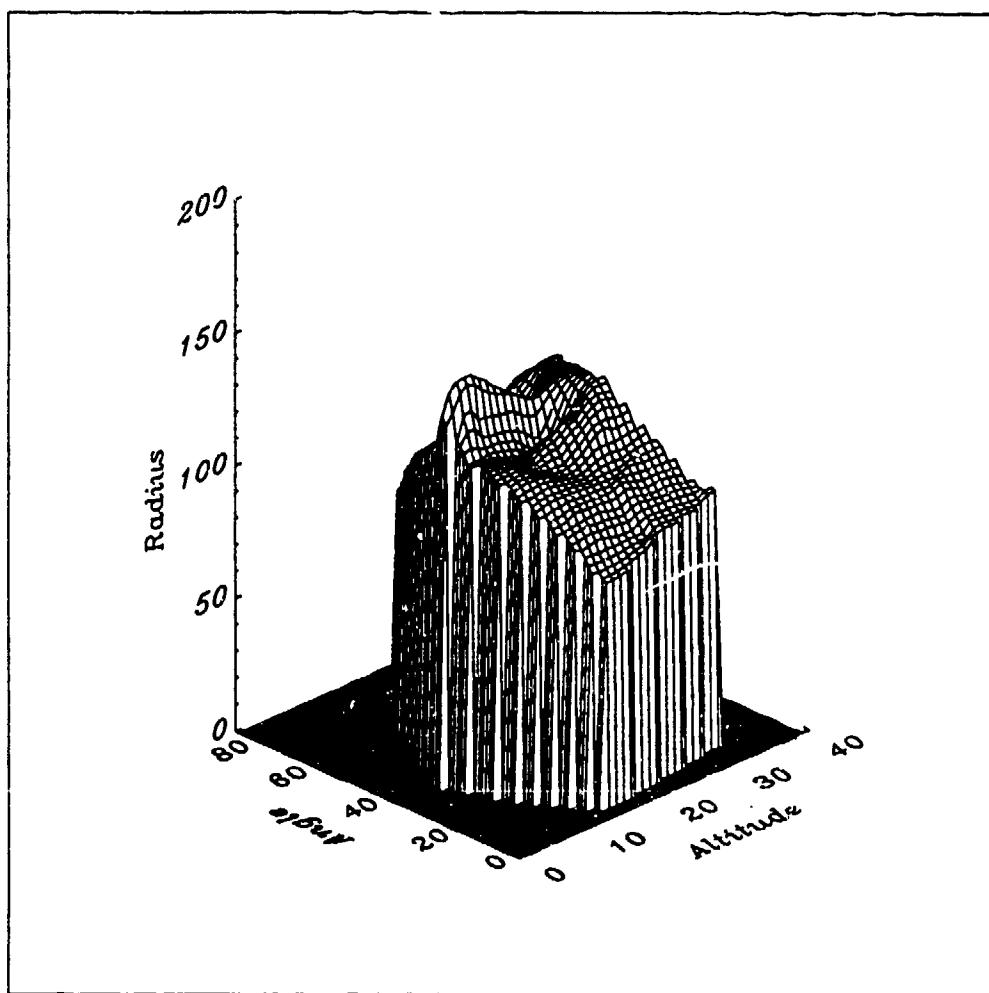
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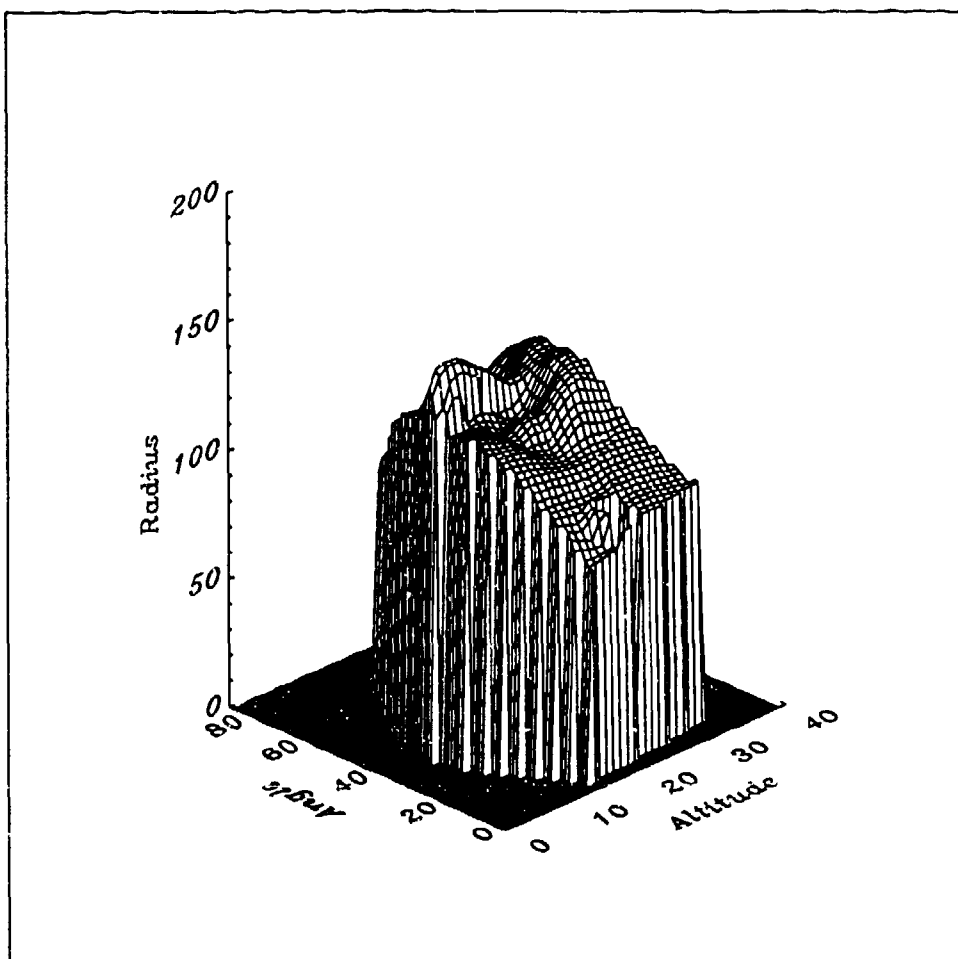
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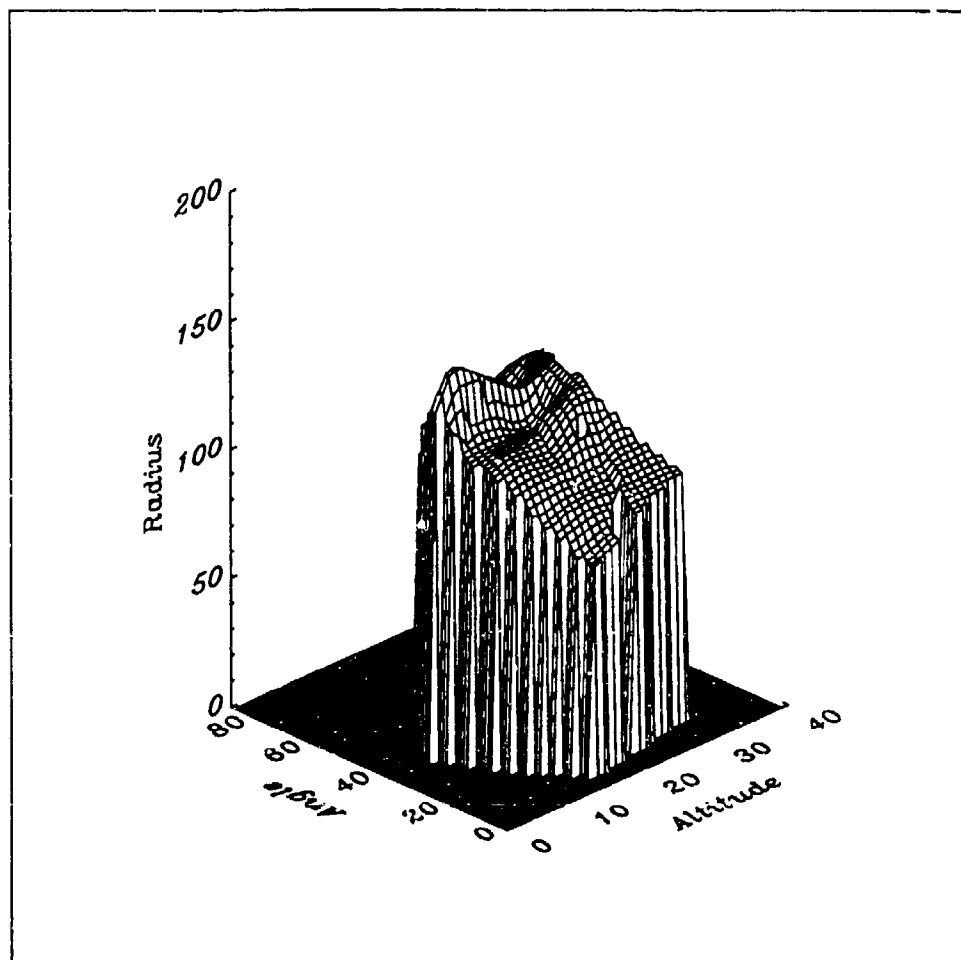
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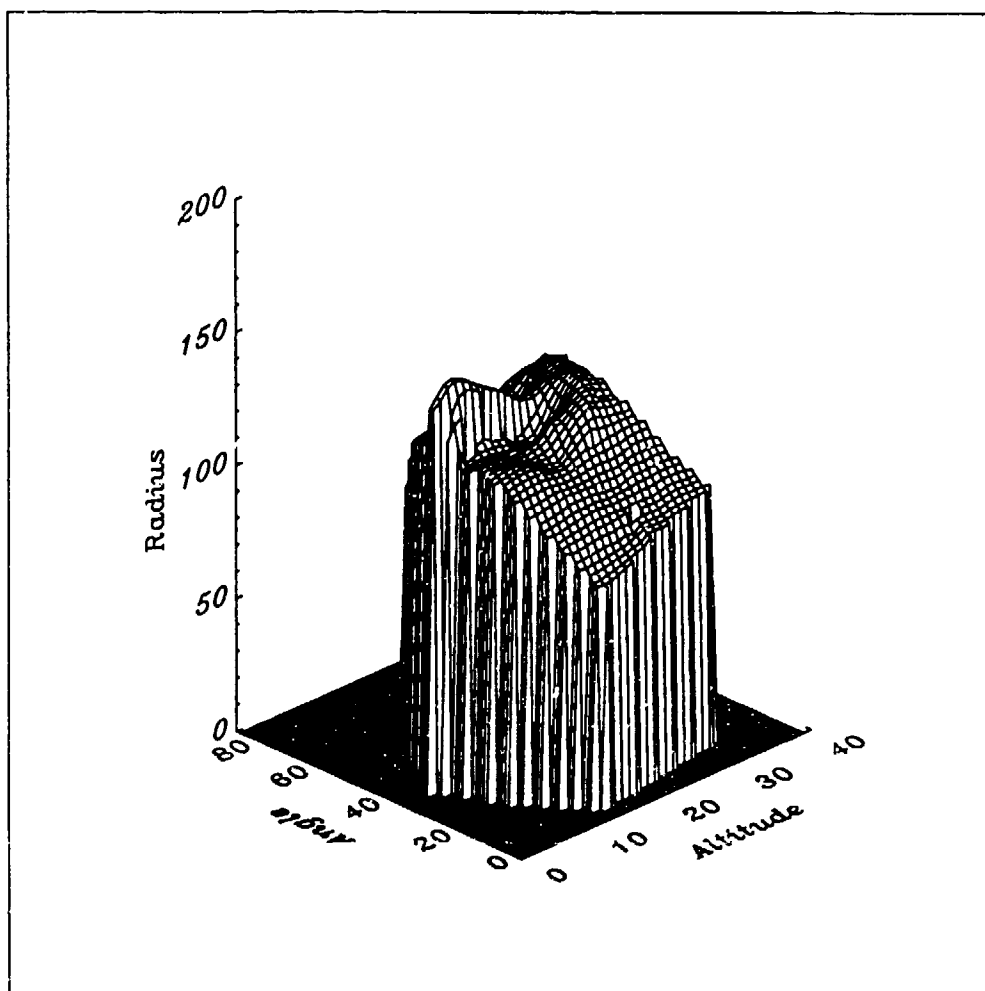
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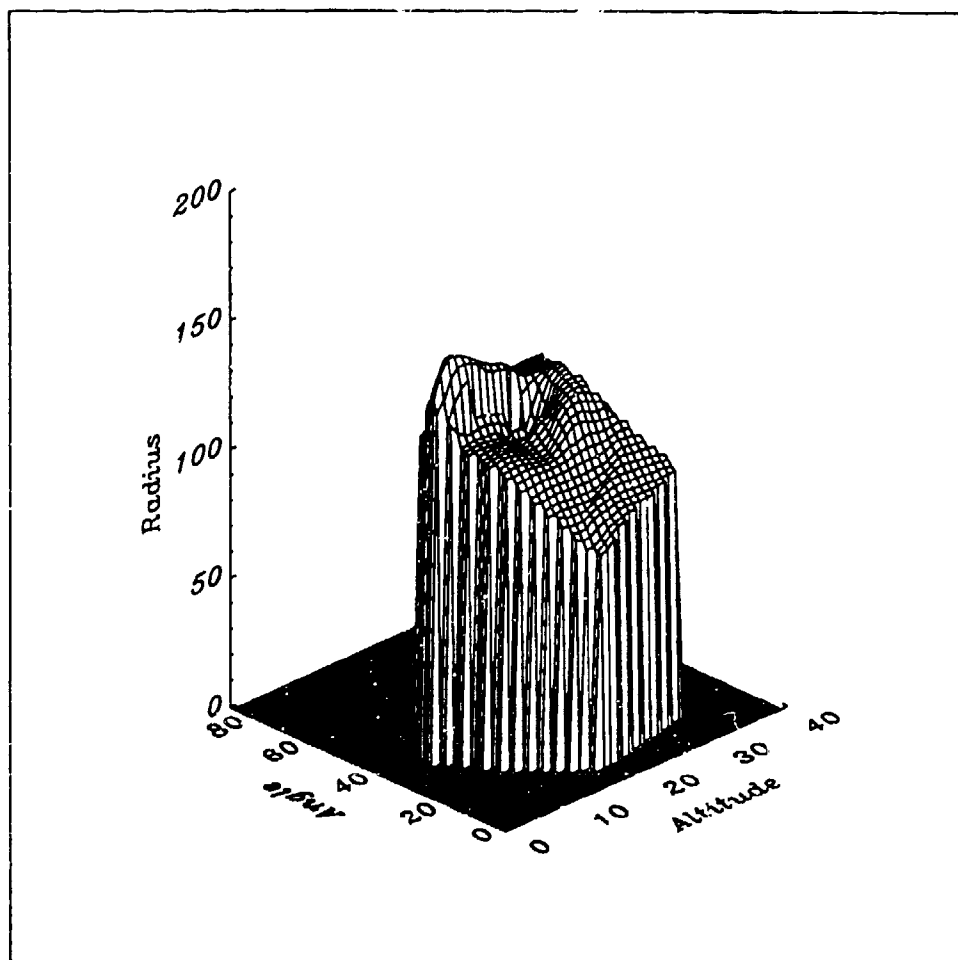
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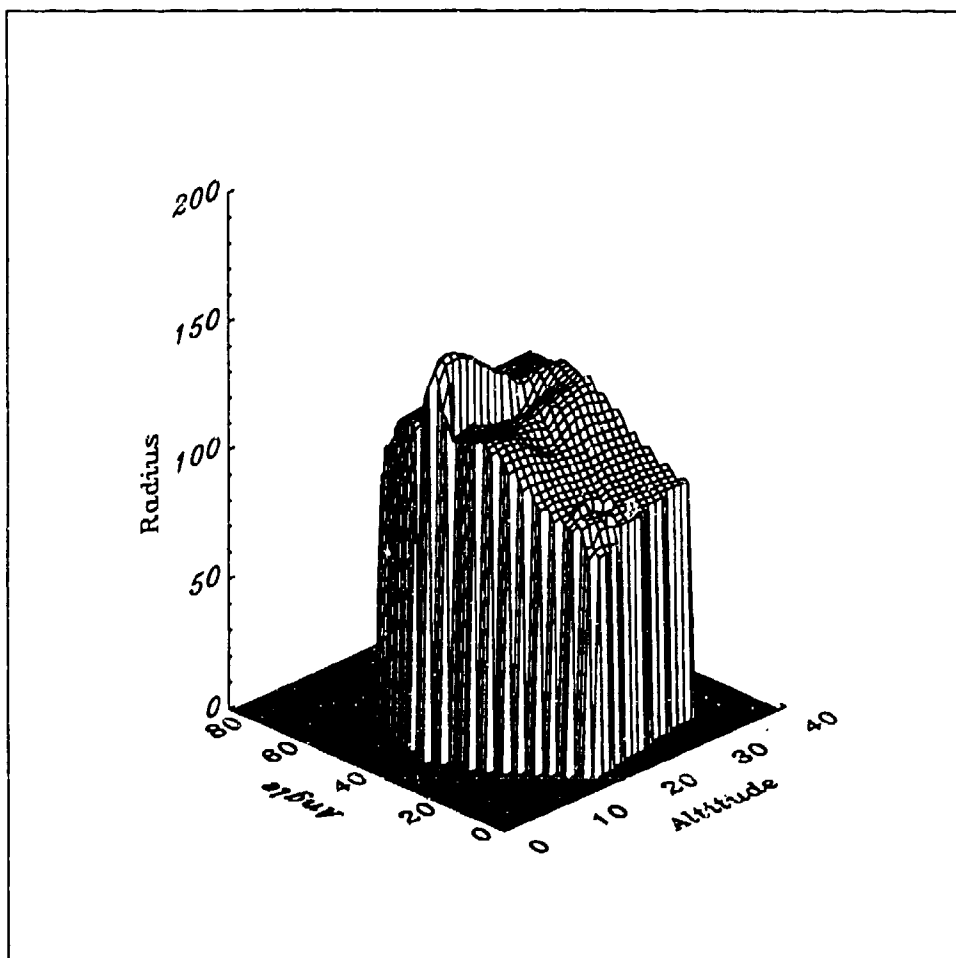
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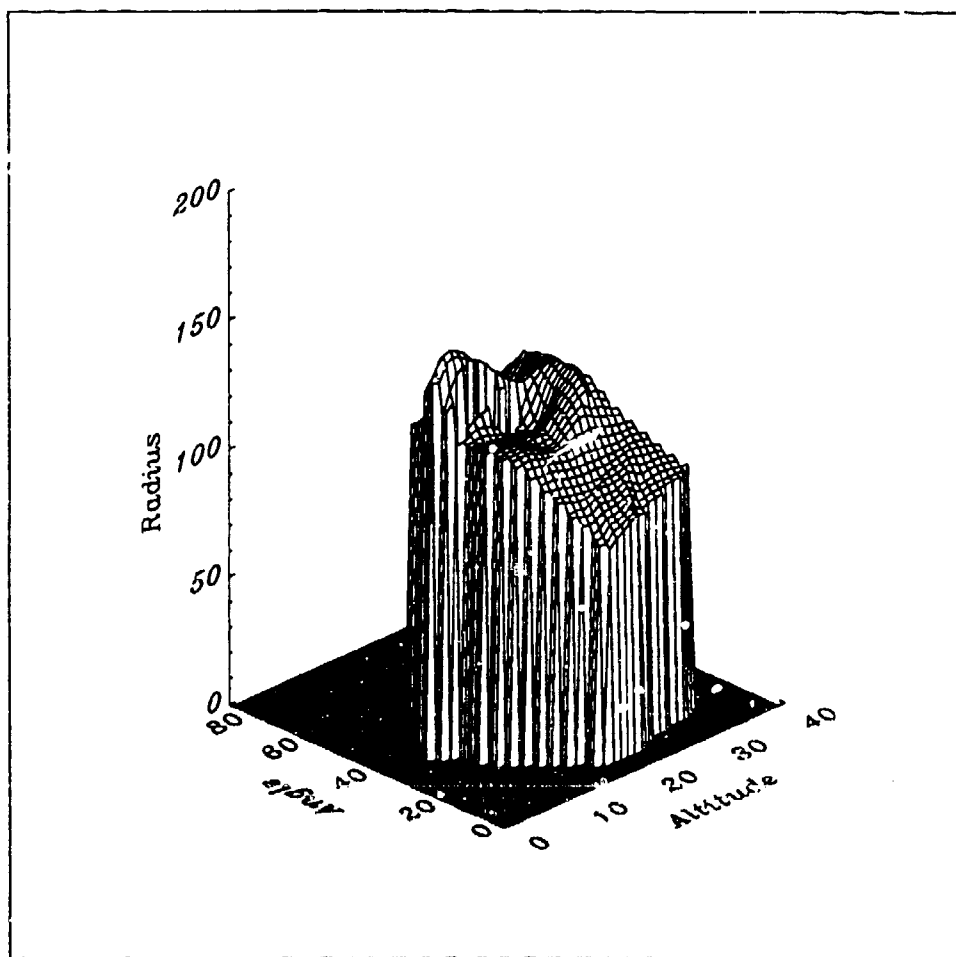
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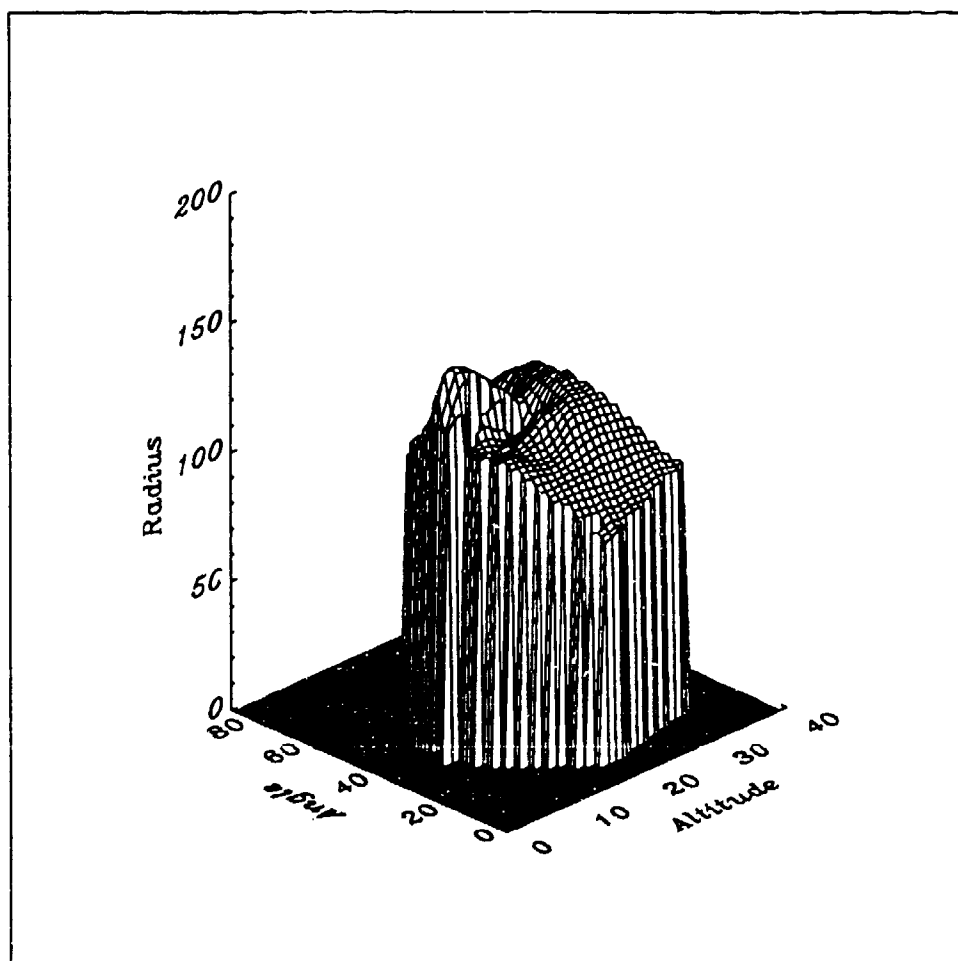
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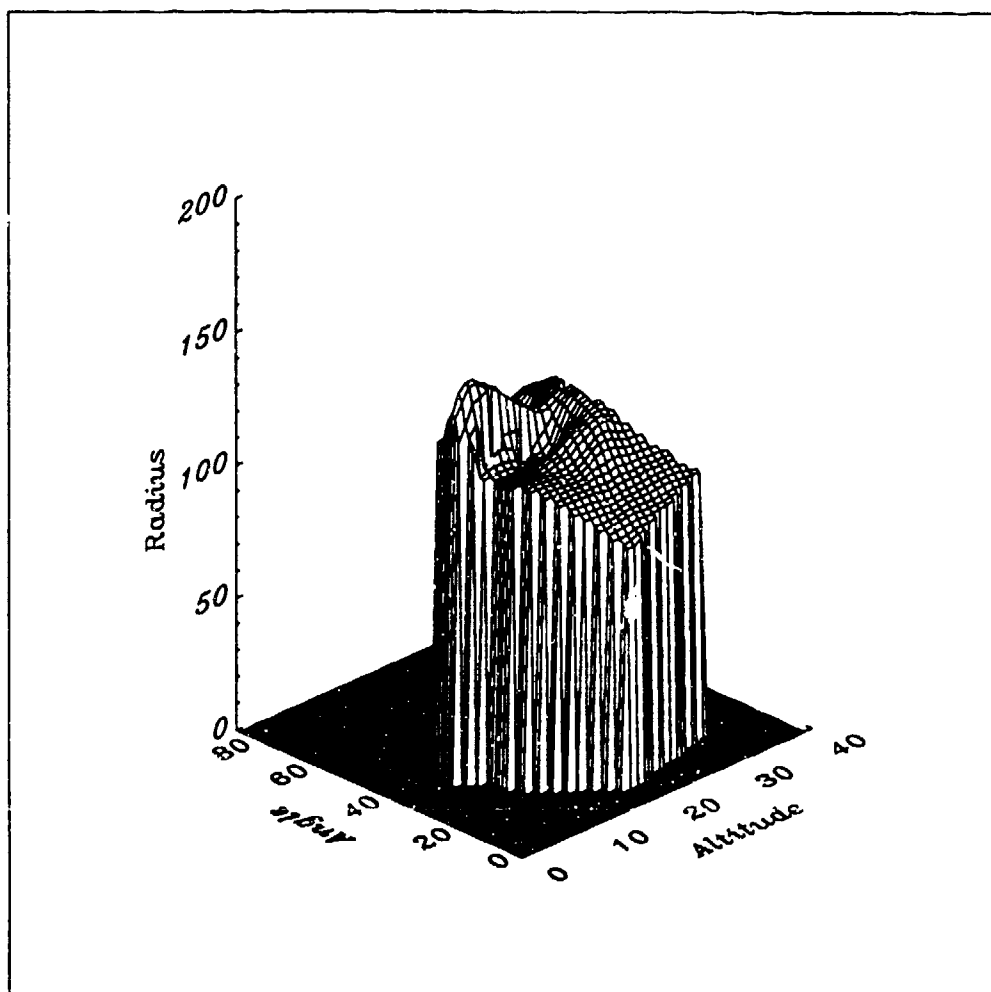
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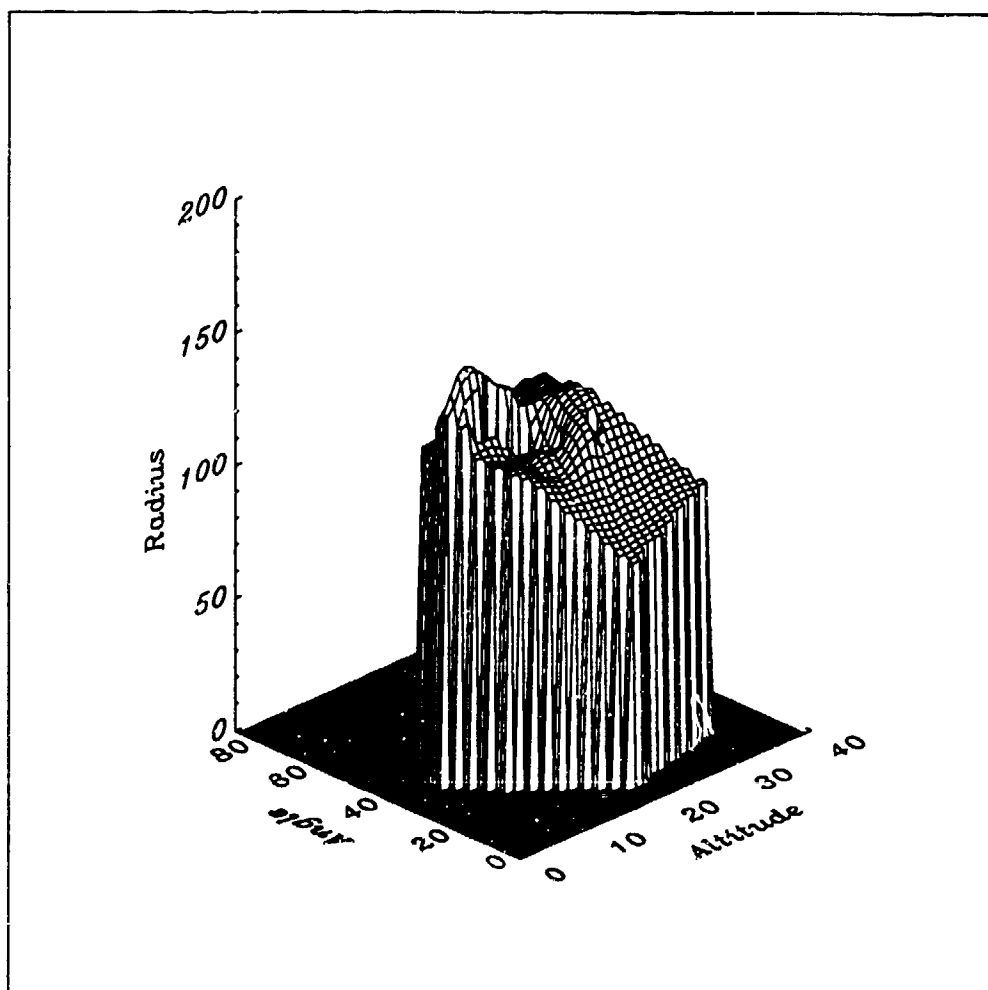
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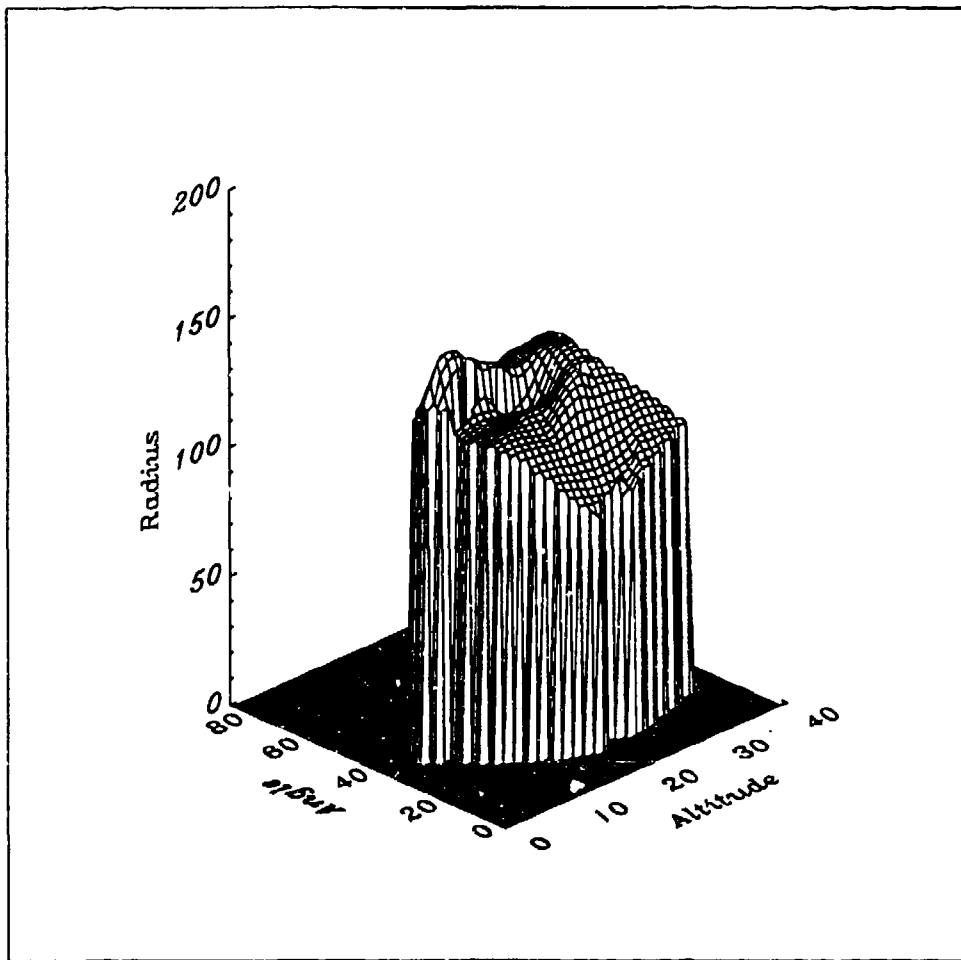
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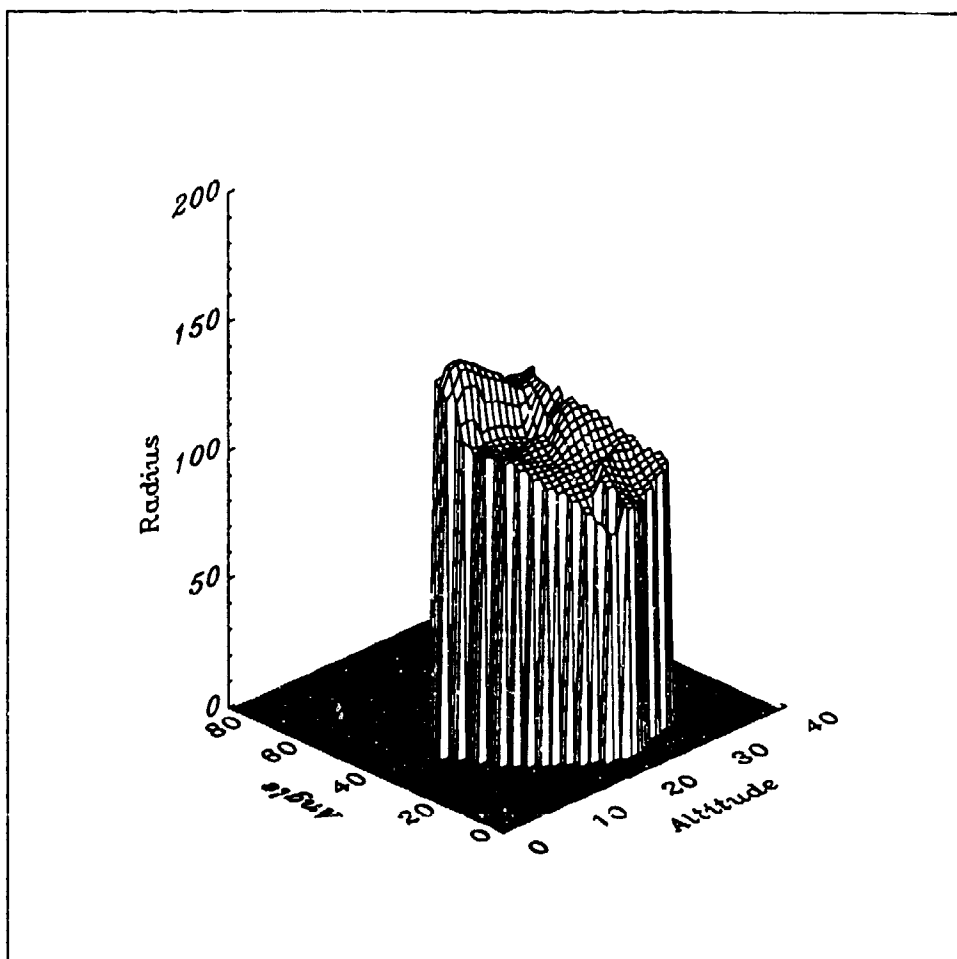
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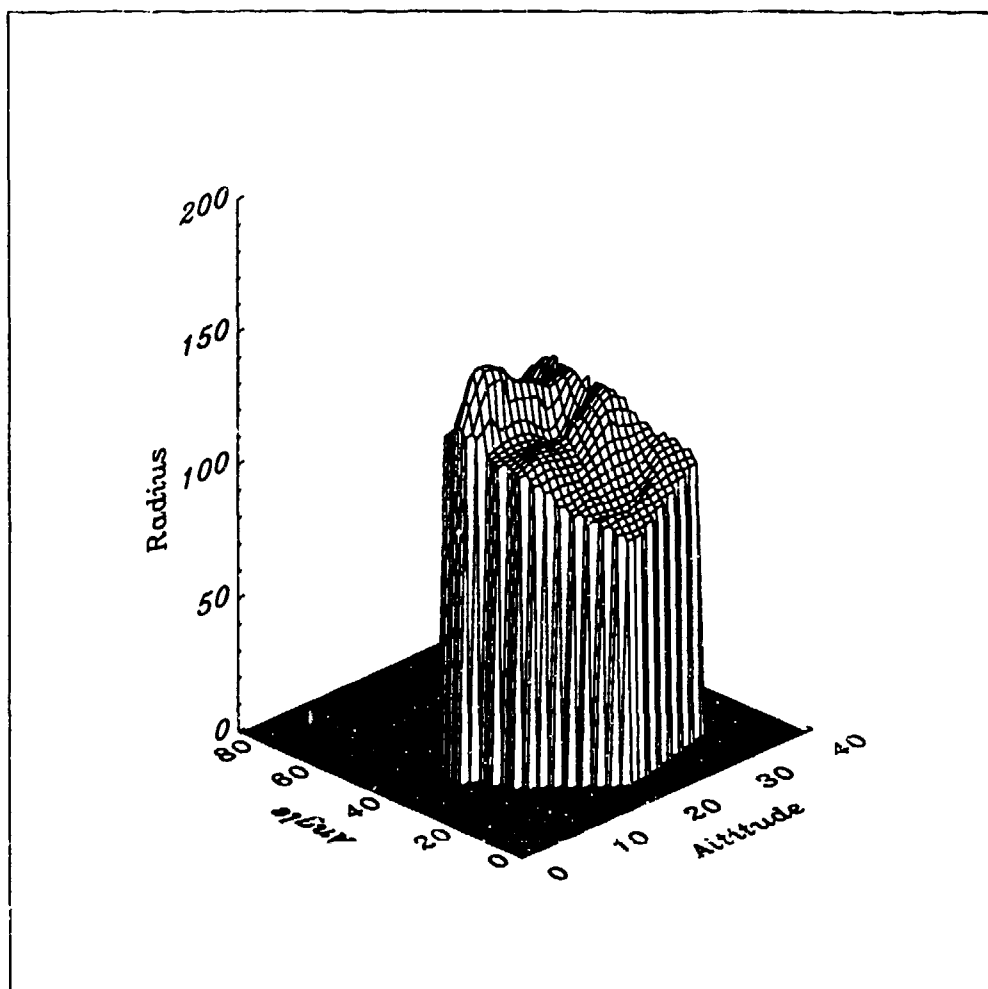
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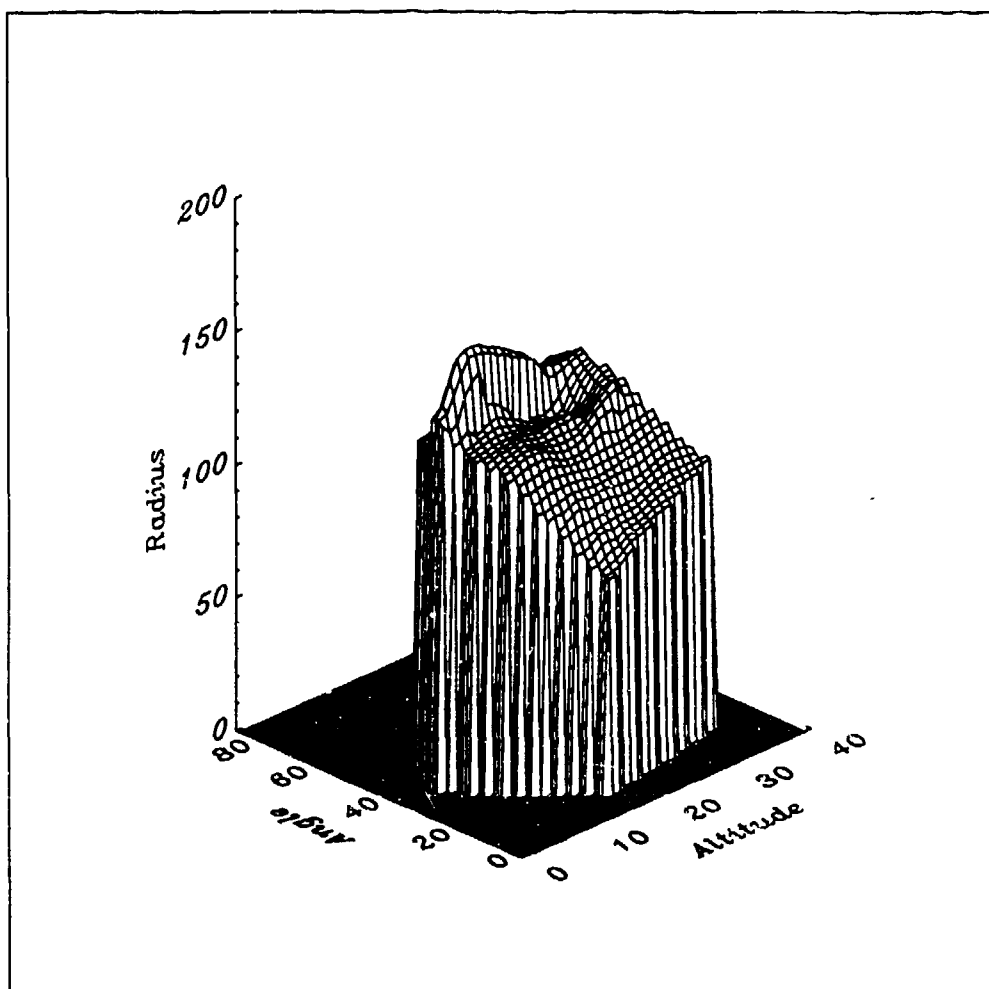
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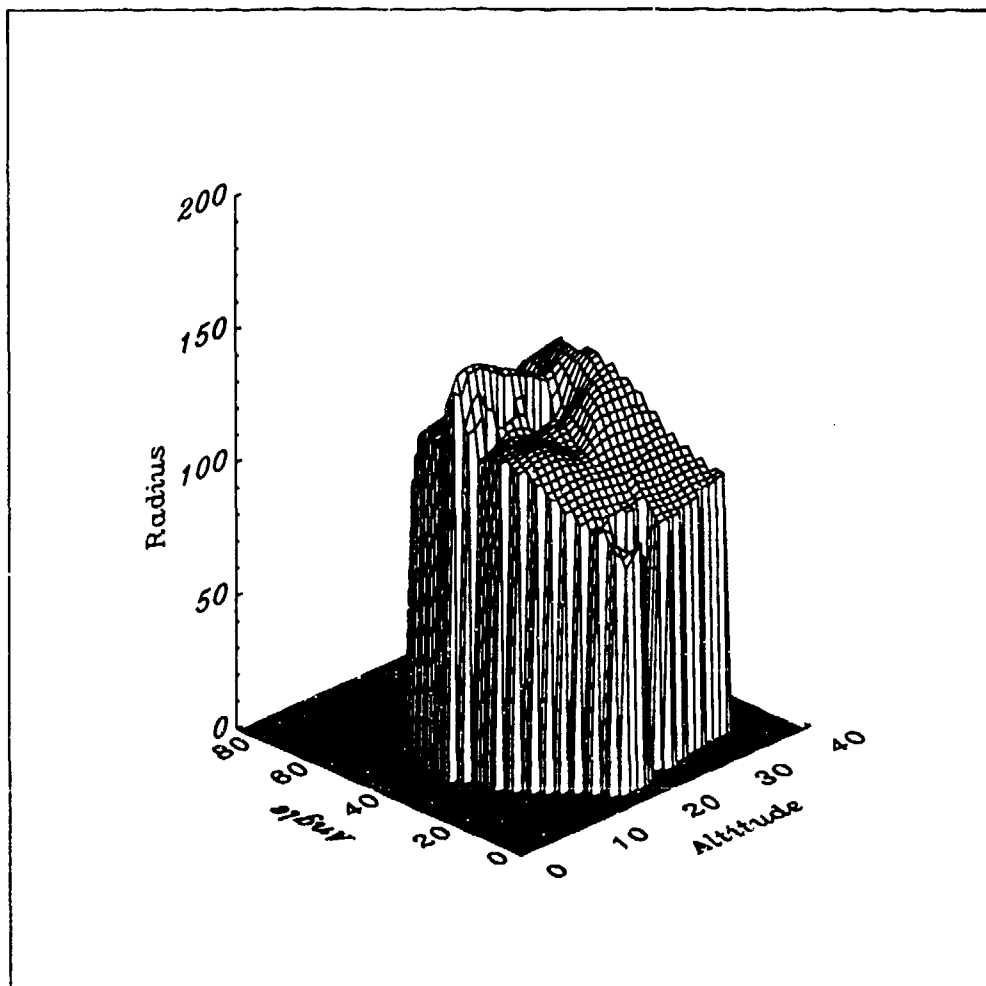
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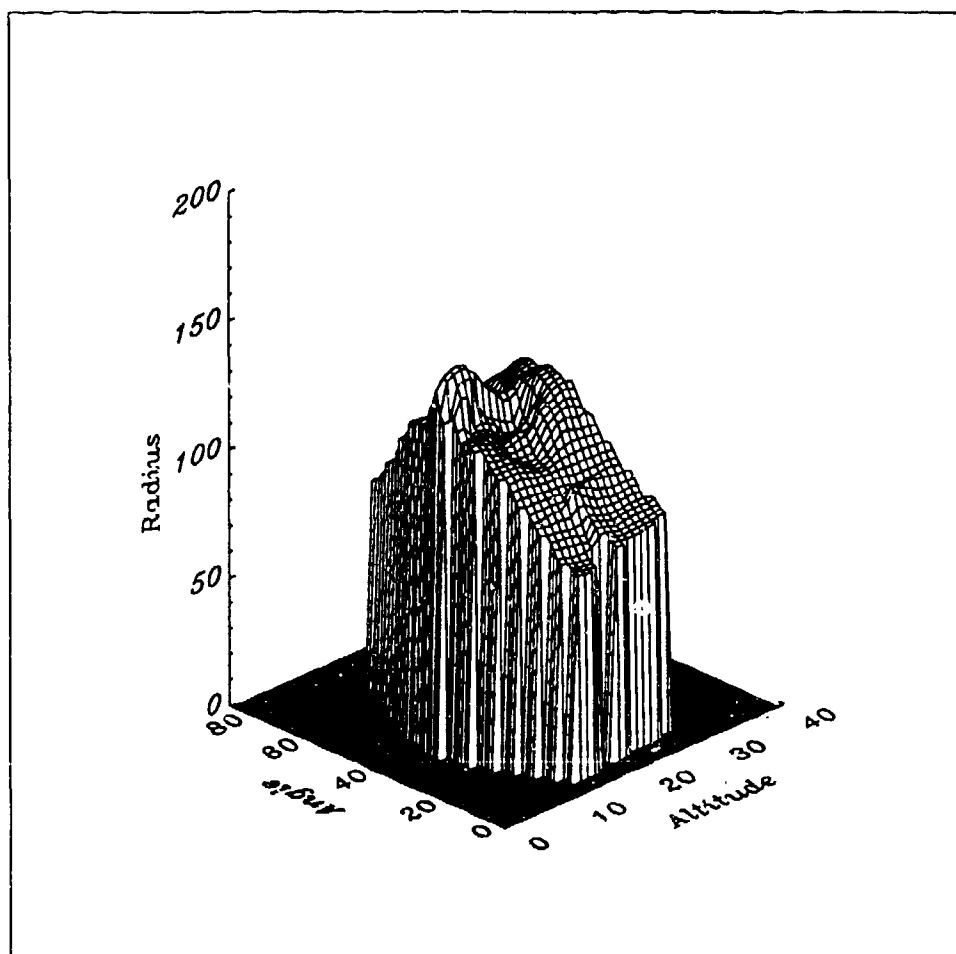
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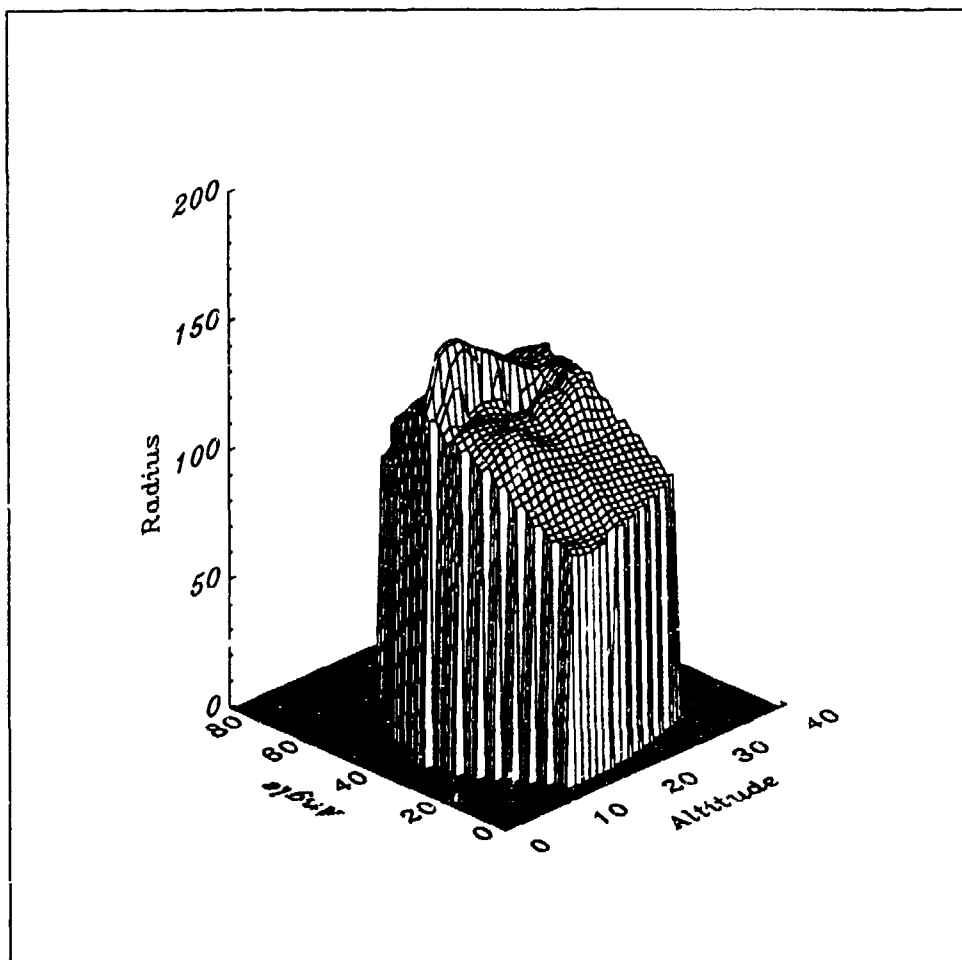
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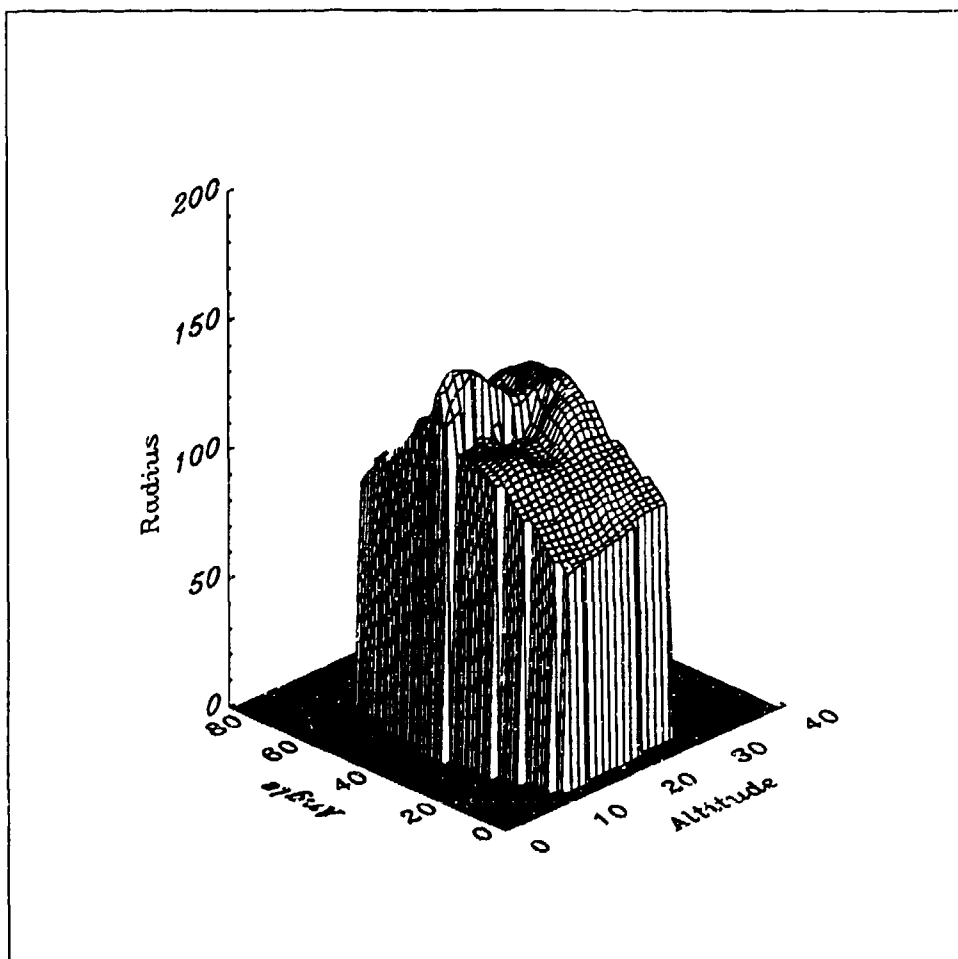
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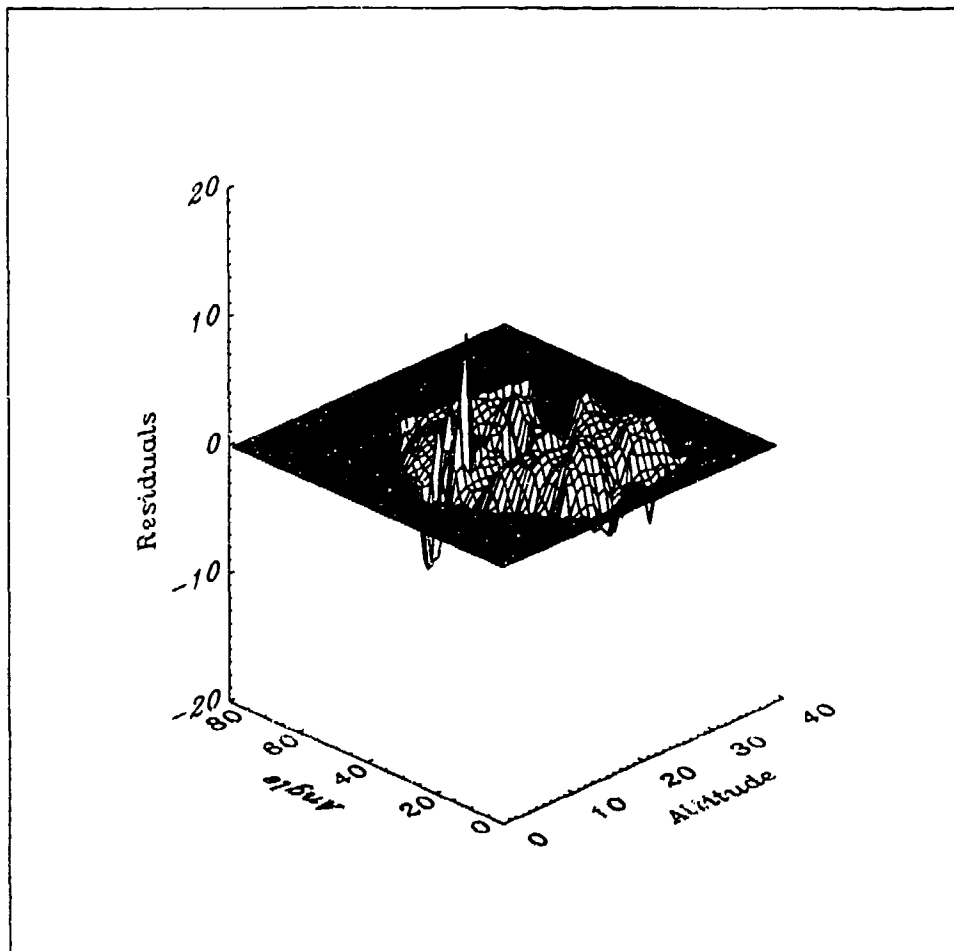
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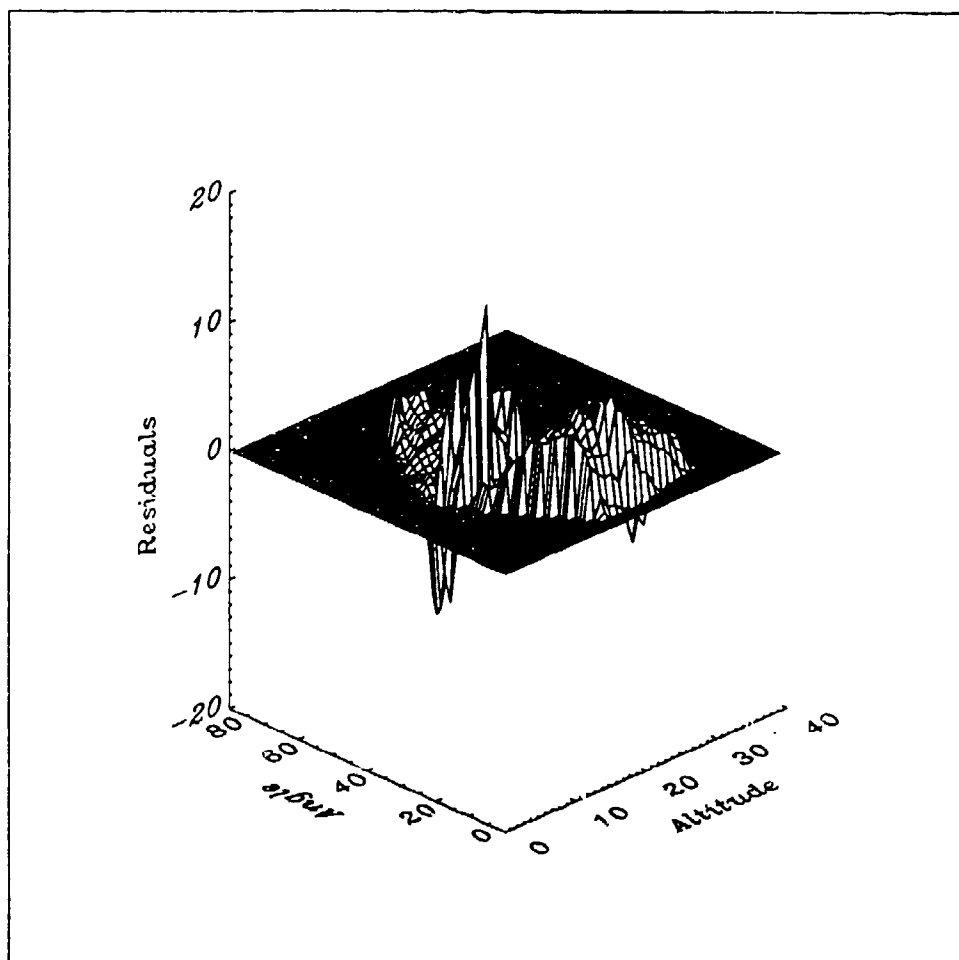
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## Appendix B. *Residual Plots*

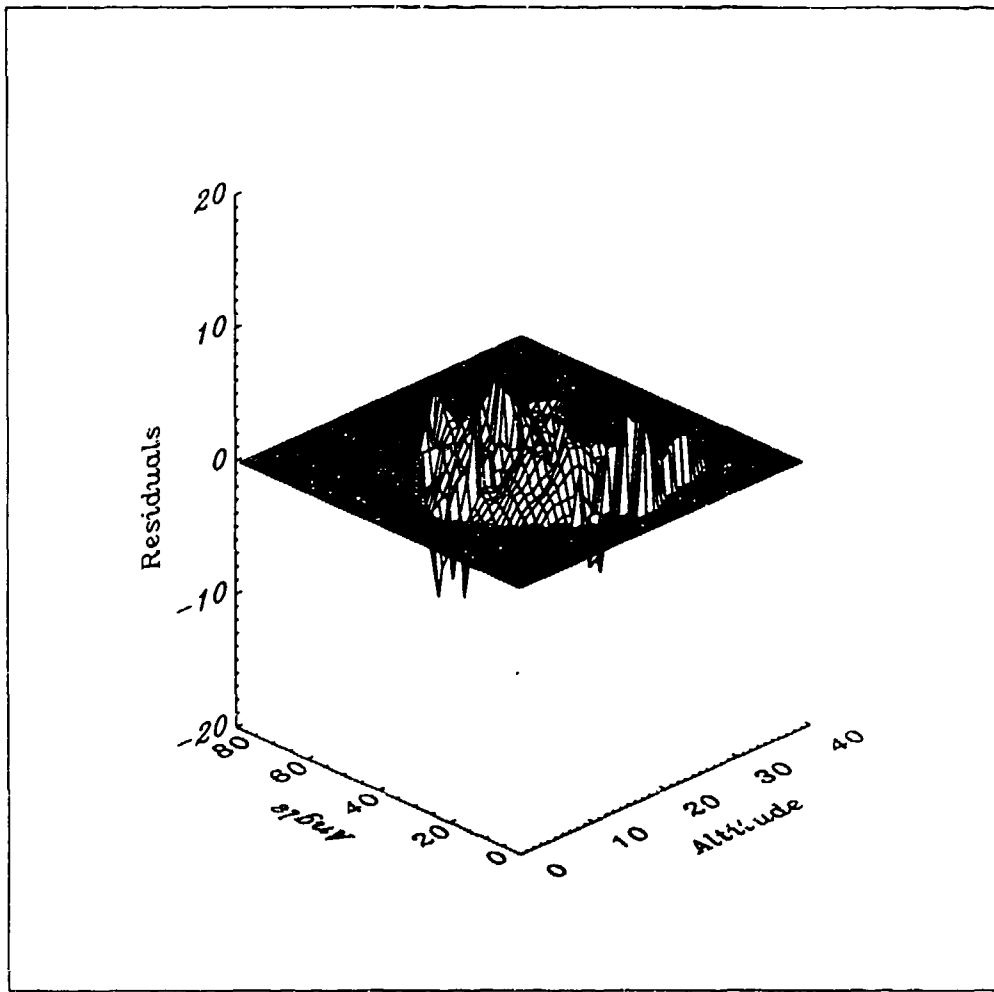
This appendix includes the residual plots obtained by differencing the subject data with the trend data. The first 25 residual data sets were used to determine the overall variogram and were used in the kriging and updating analysis. The next five data sets were excluded from the overall variogram analysis, the kriging analysis, and the updating analysis because the variograms were not consistent with the set of 25. These five data sets were included in the trend. The final seven data sets were considered for the kriging and updating procedures. However, only the first five sets followed the standard variogram pattern and were used for kriging and updating the surface estimates.



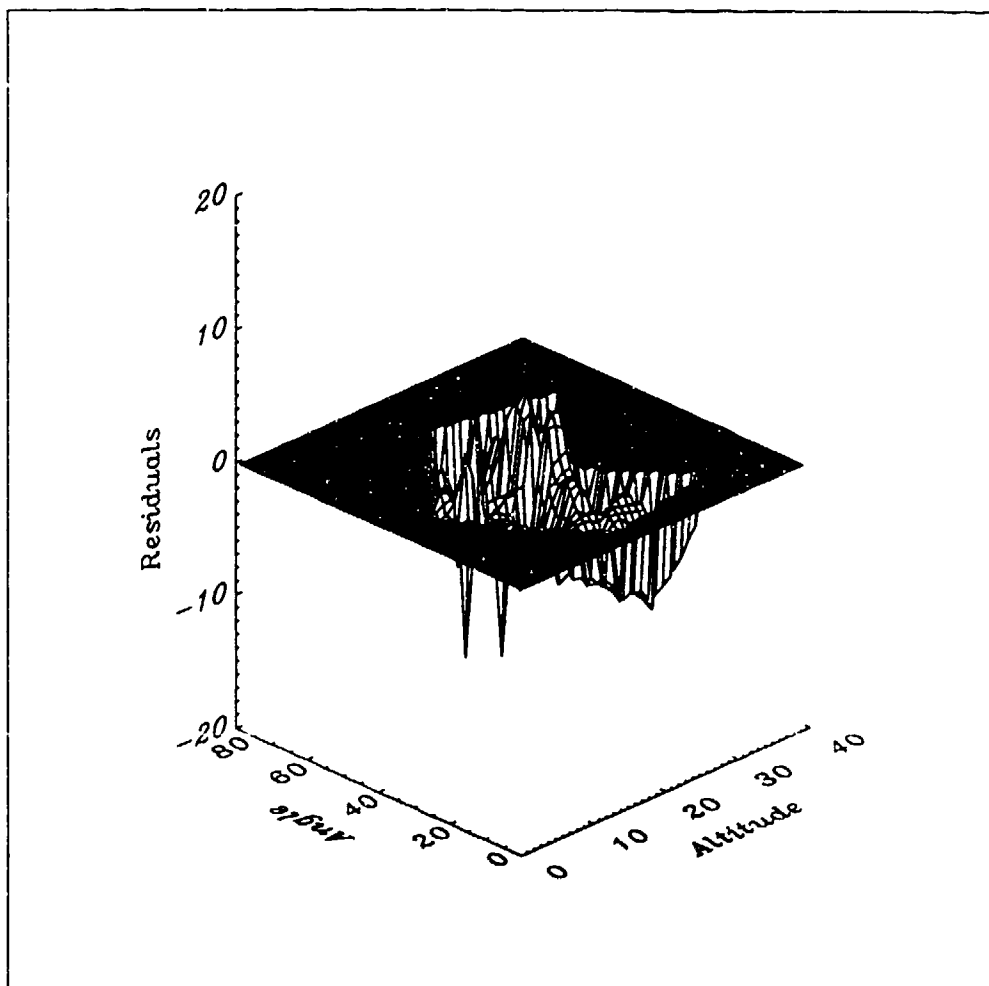
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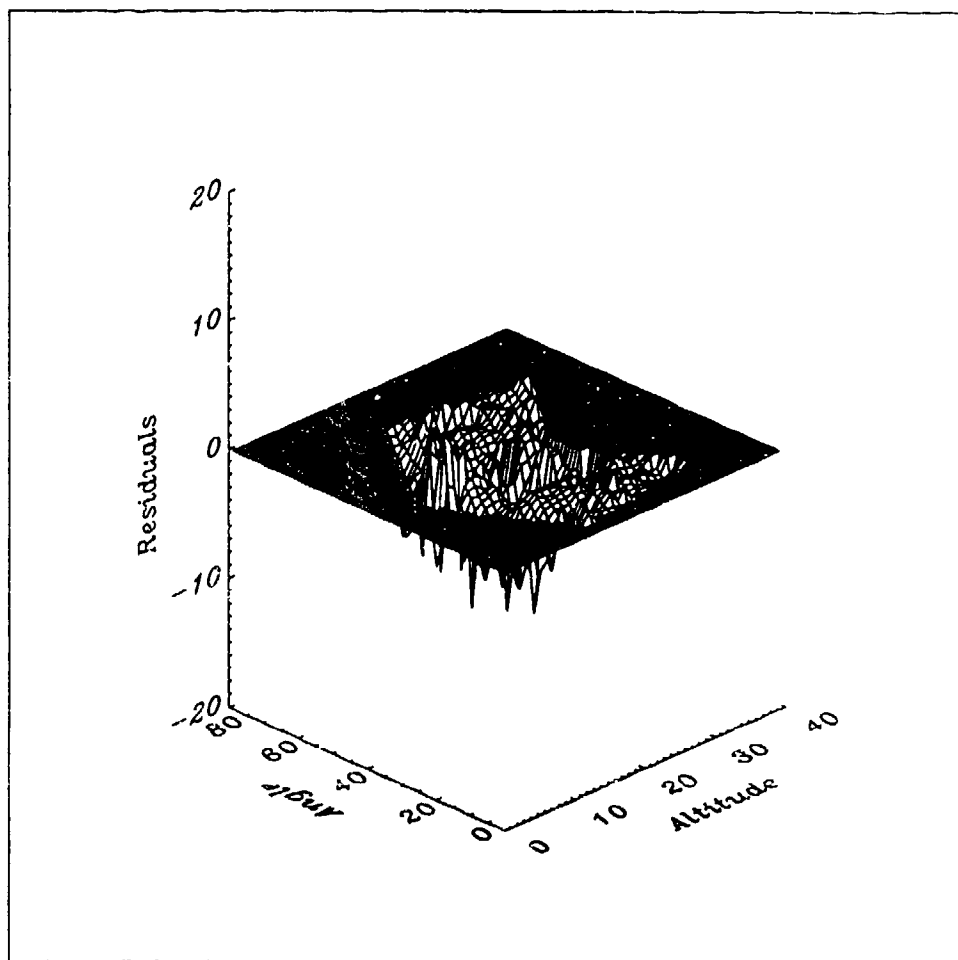
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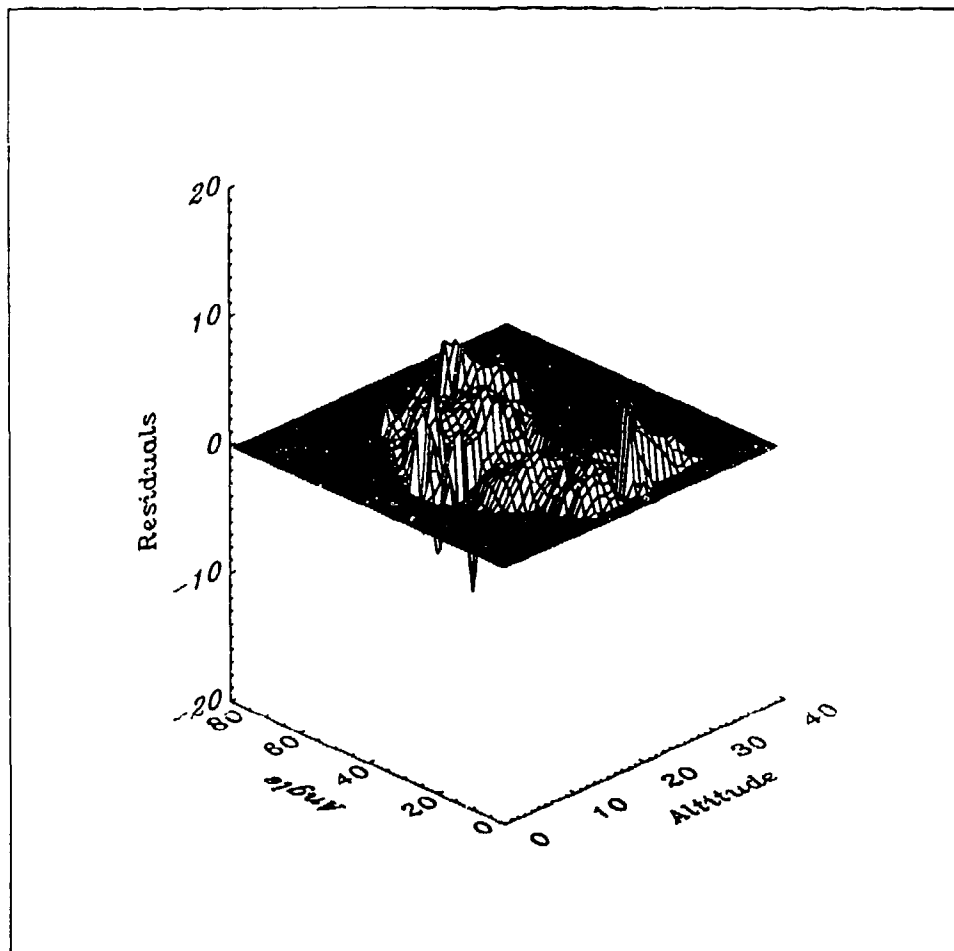
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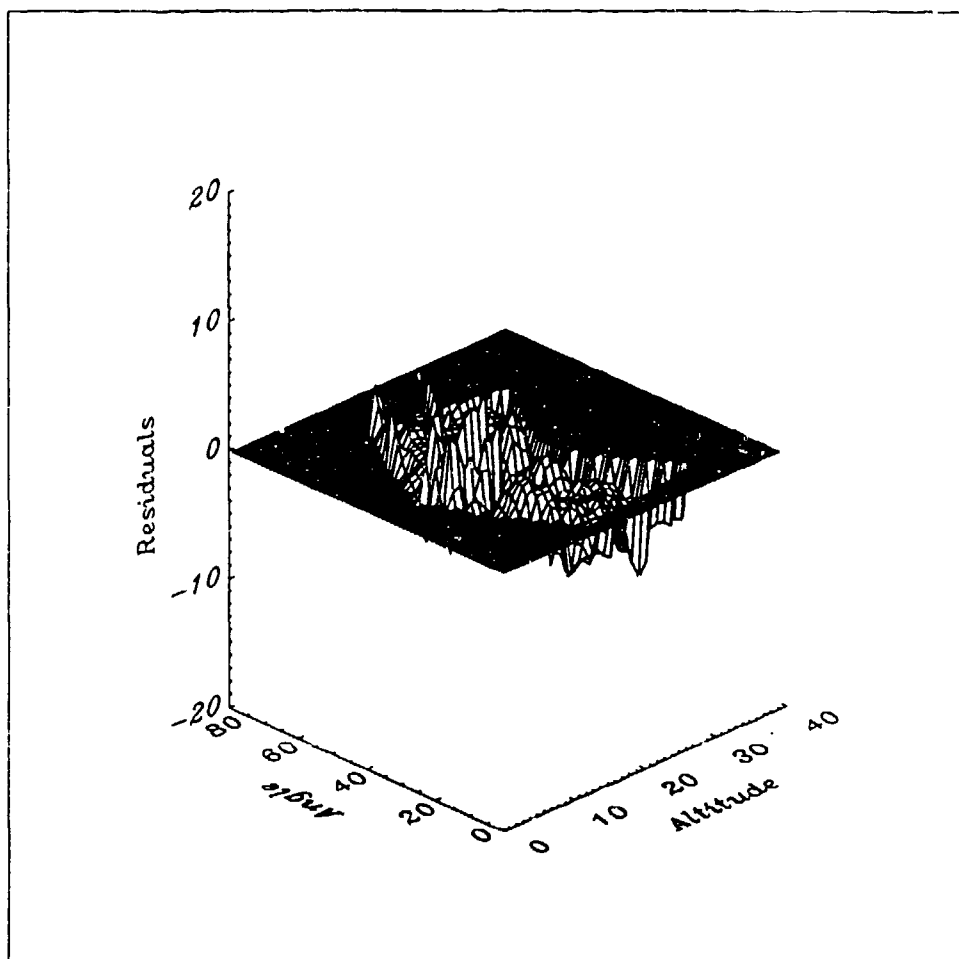
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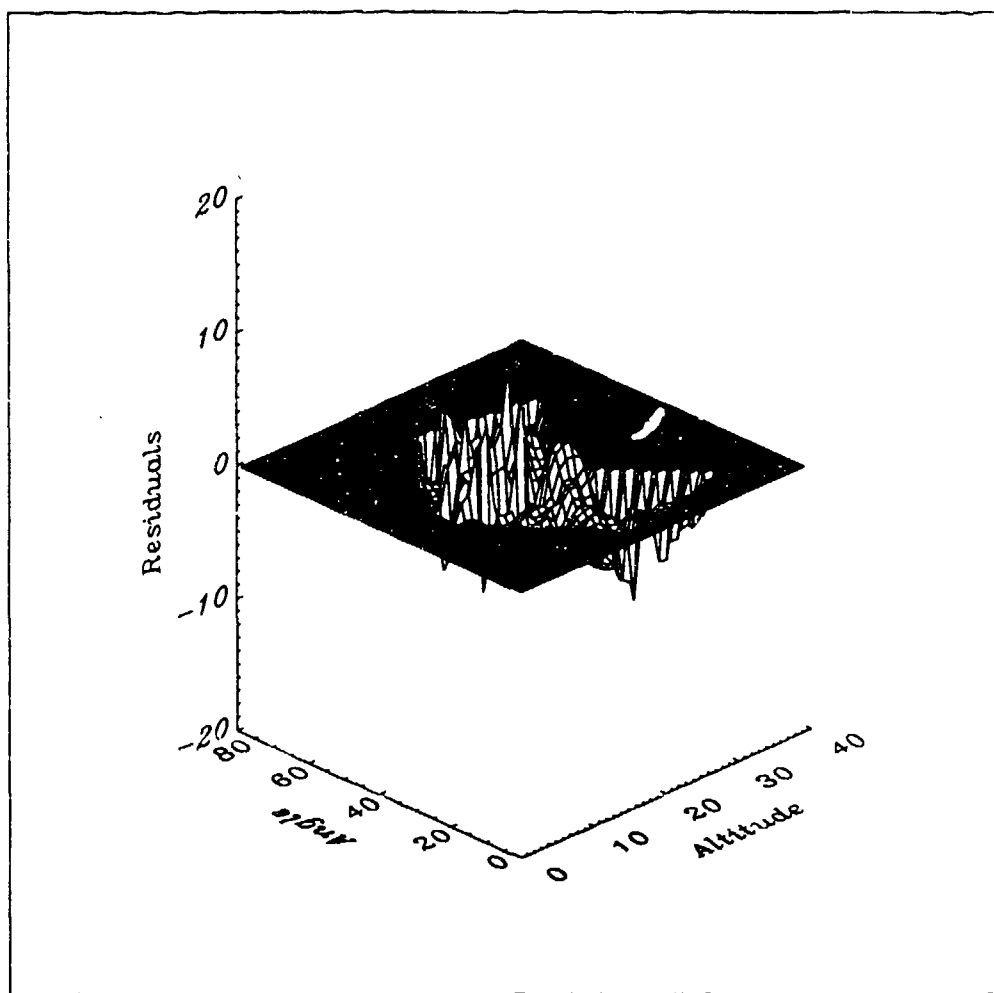
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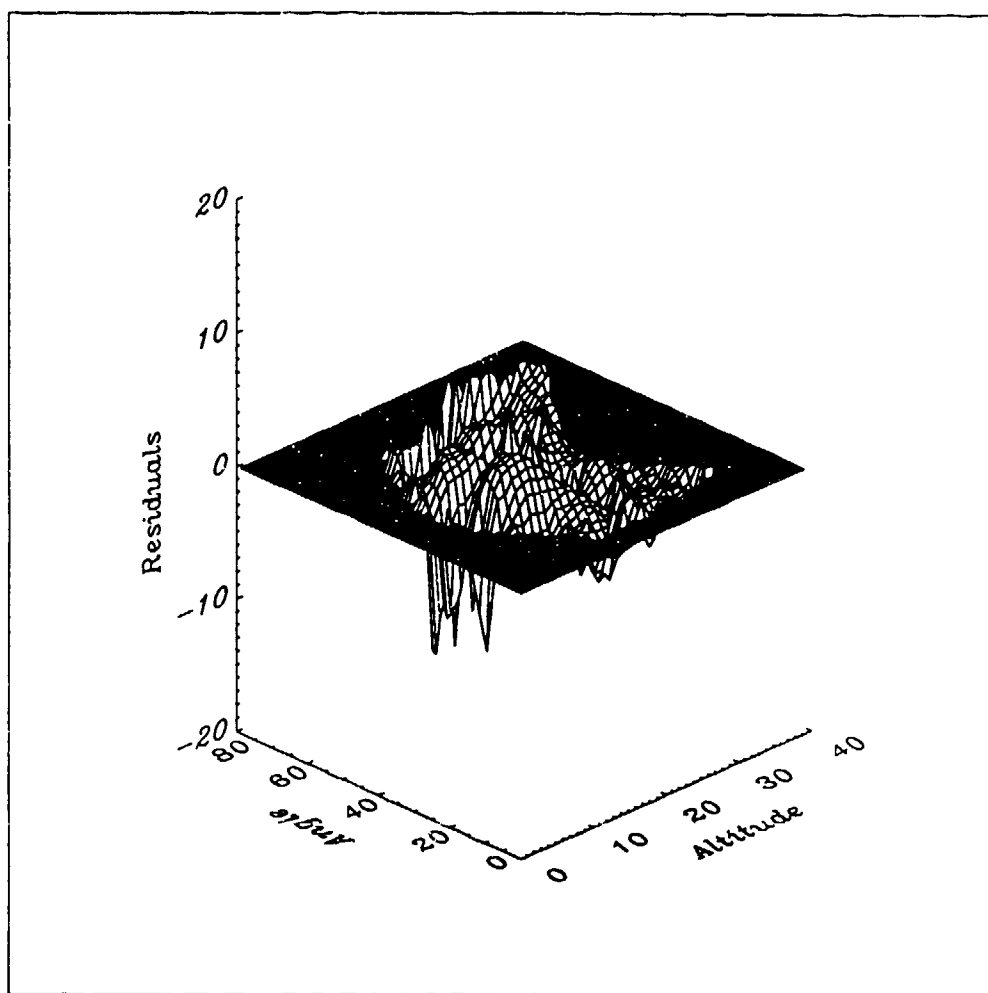
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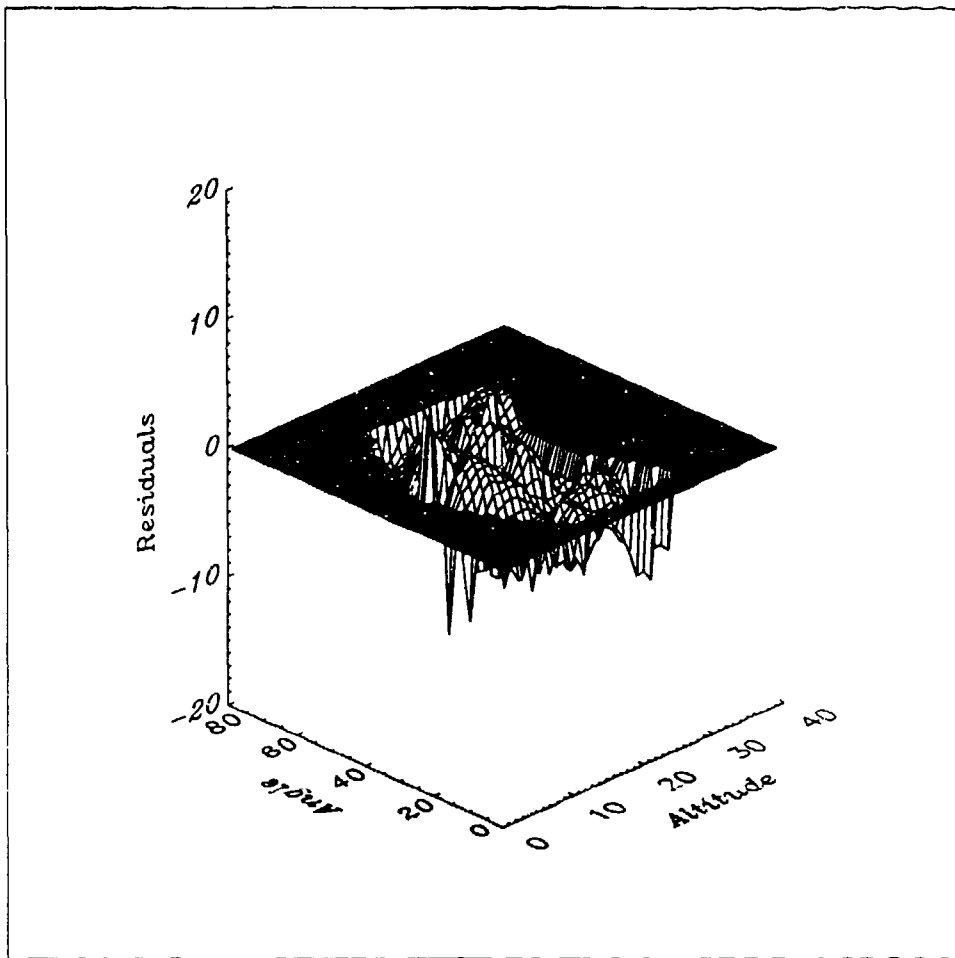
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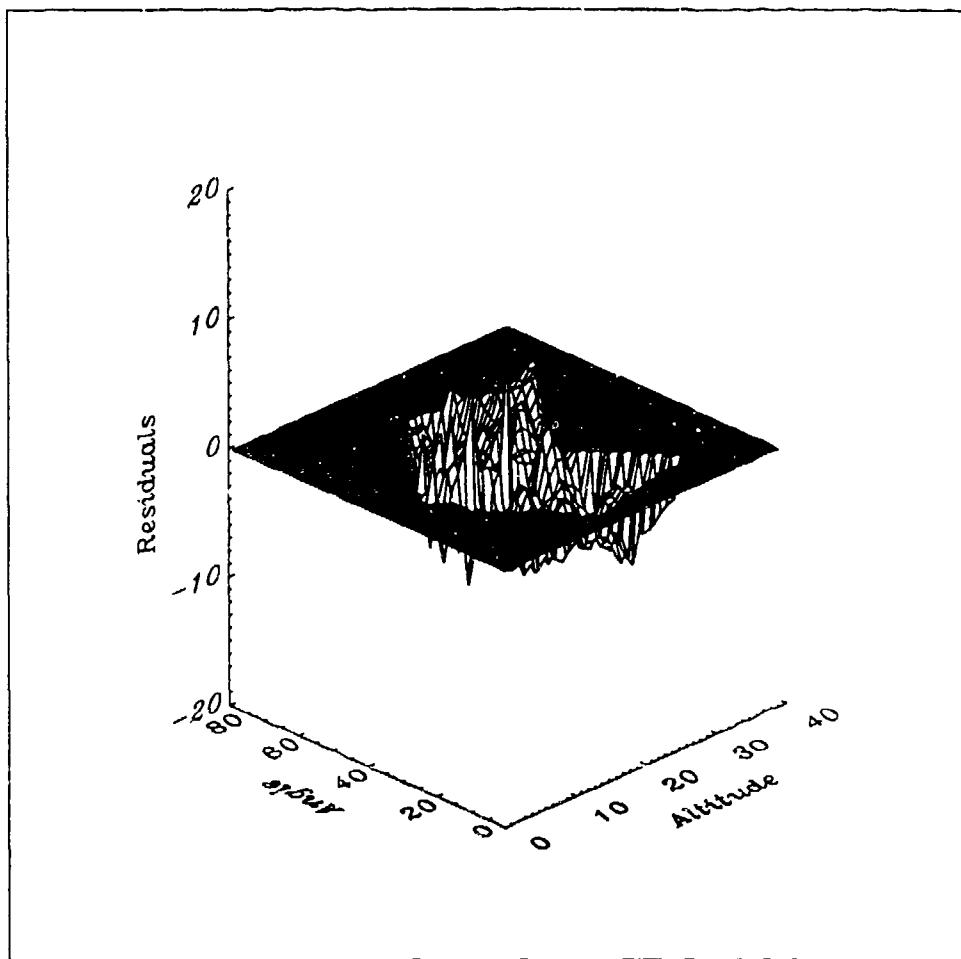
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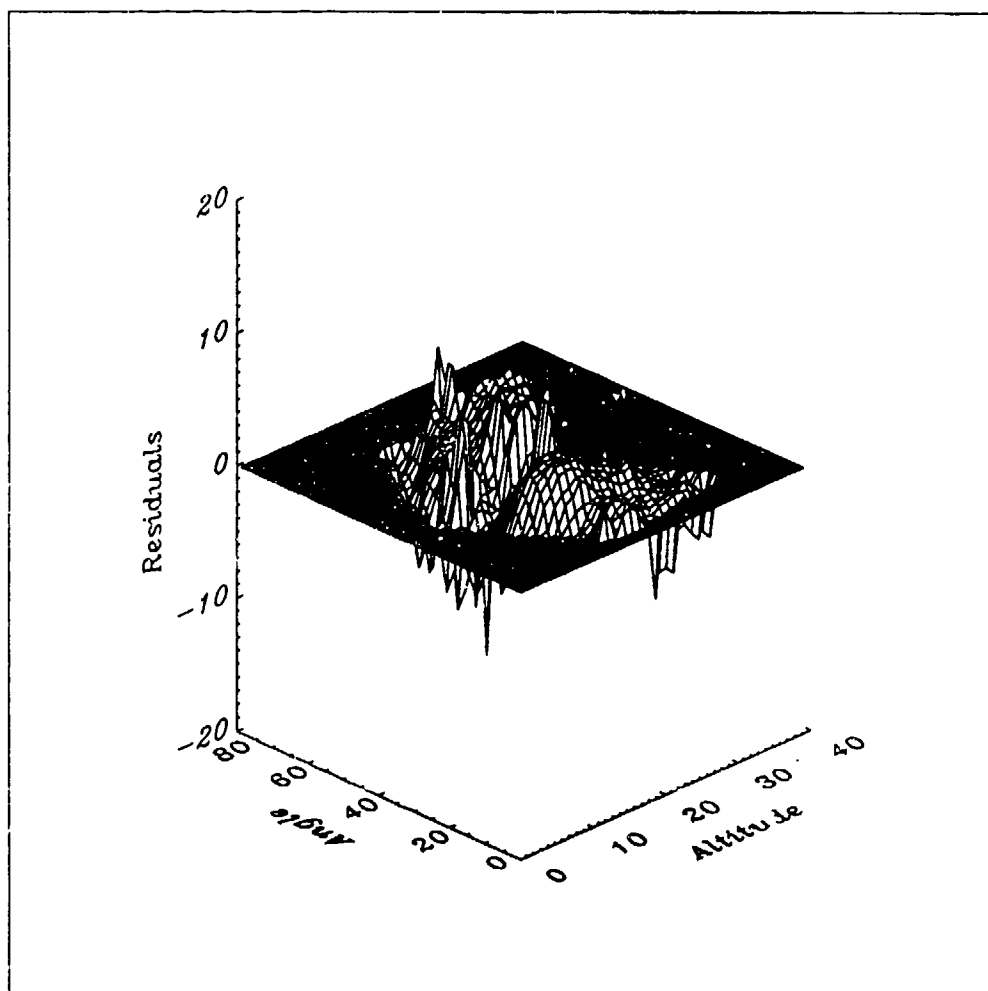
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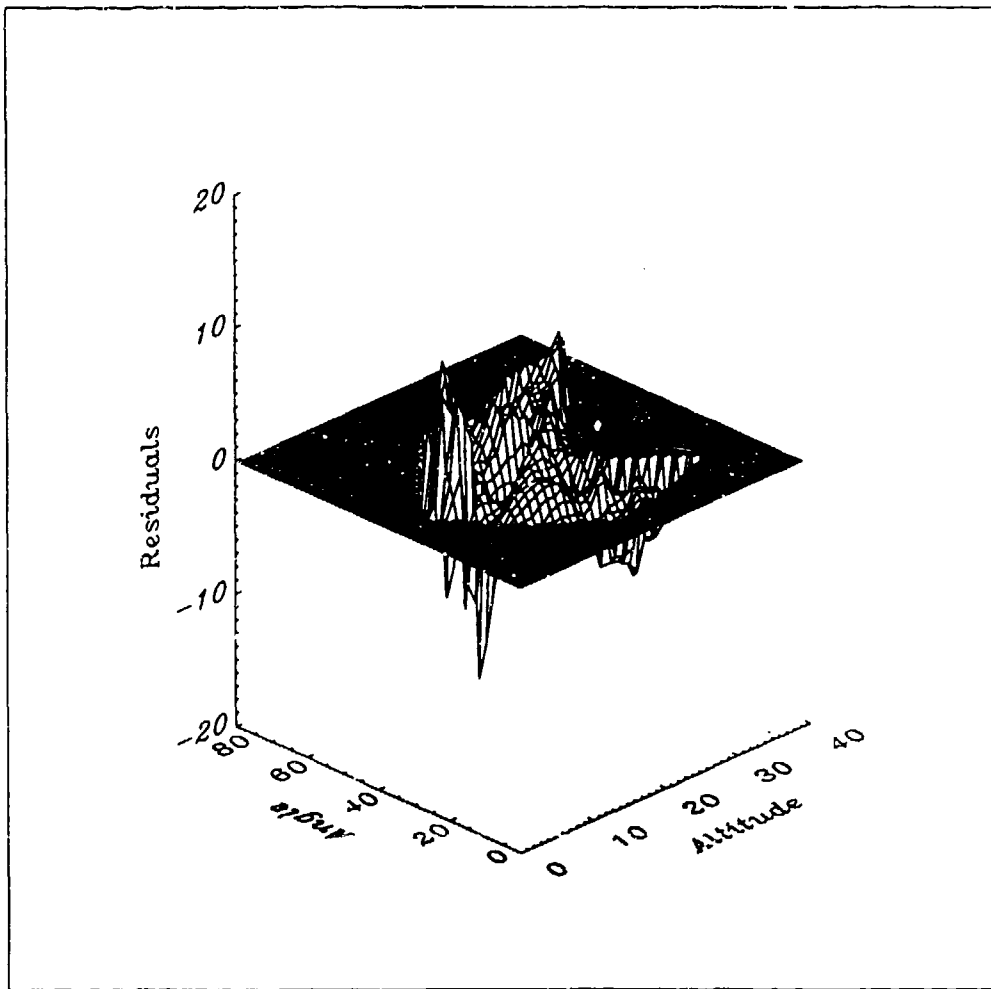
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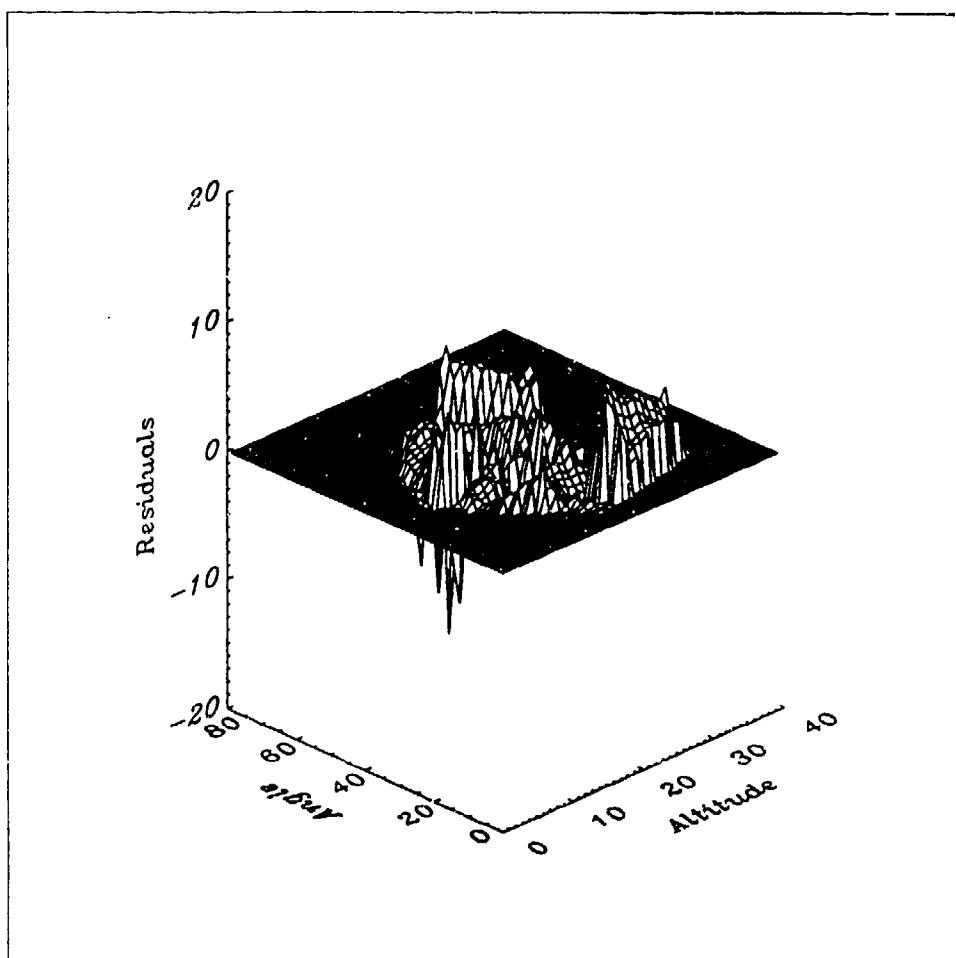
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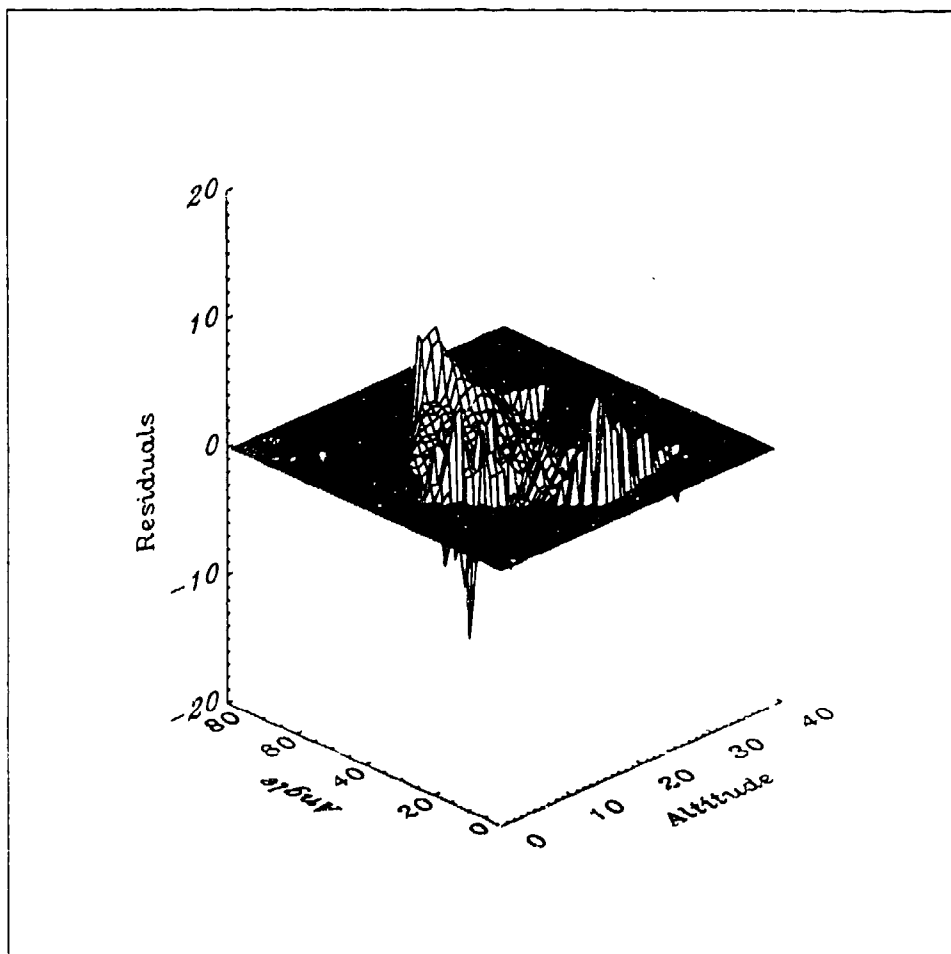
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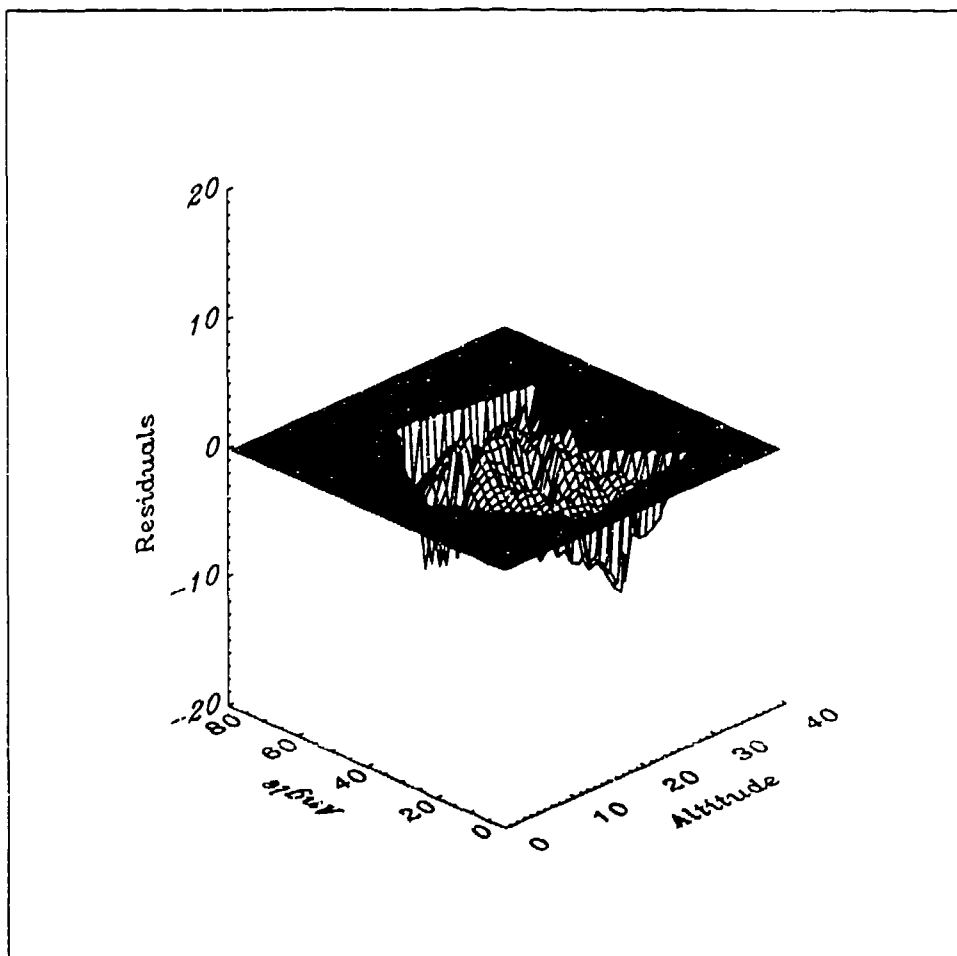
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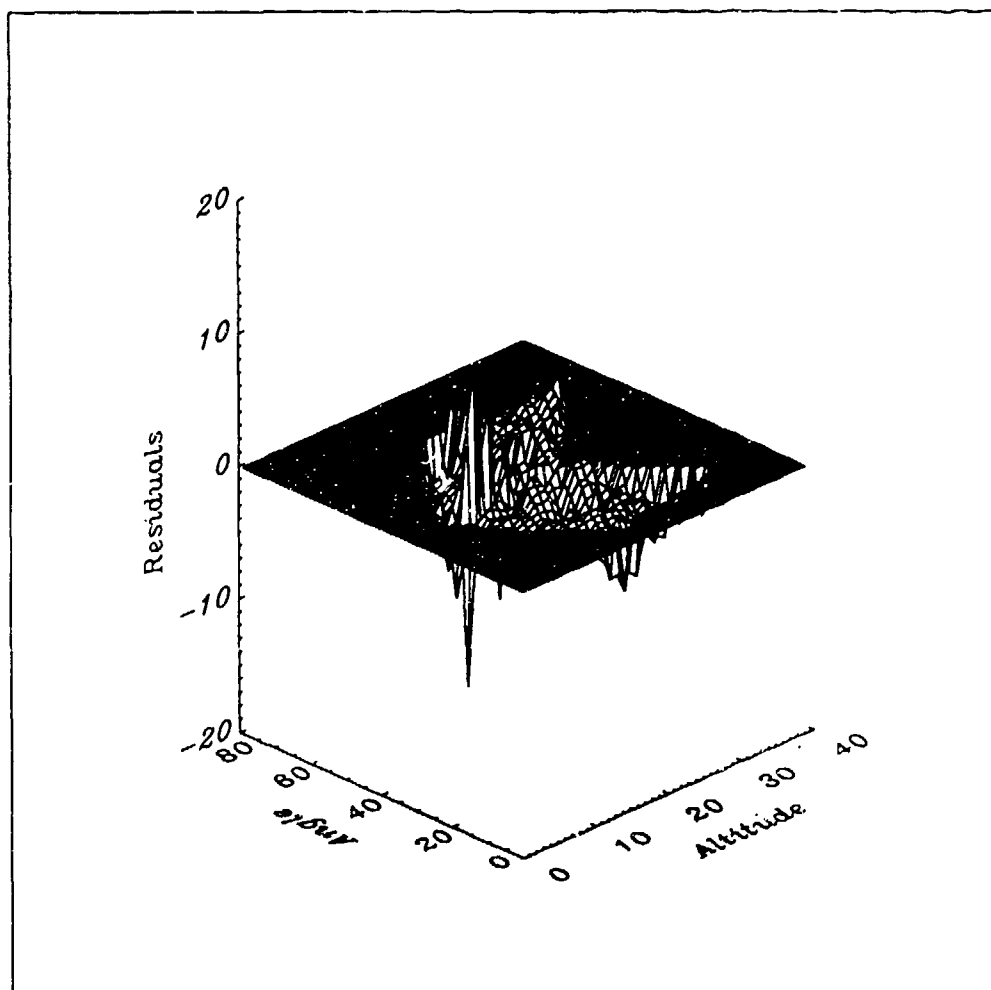
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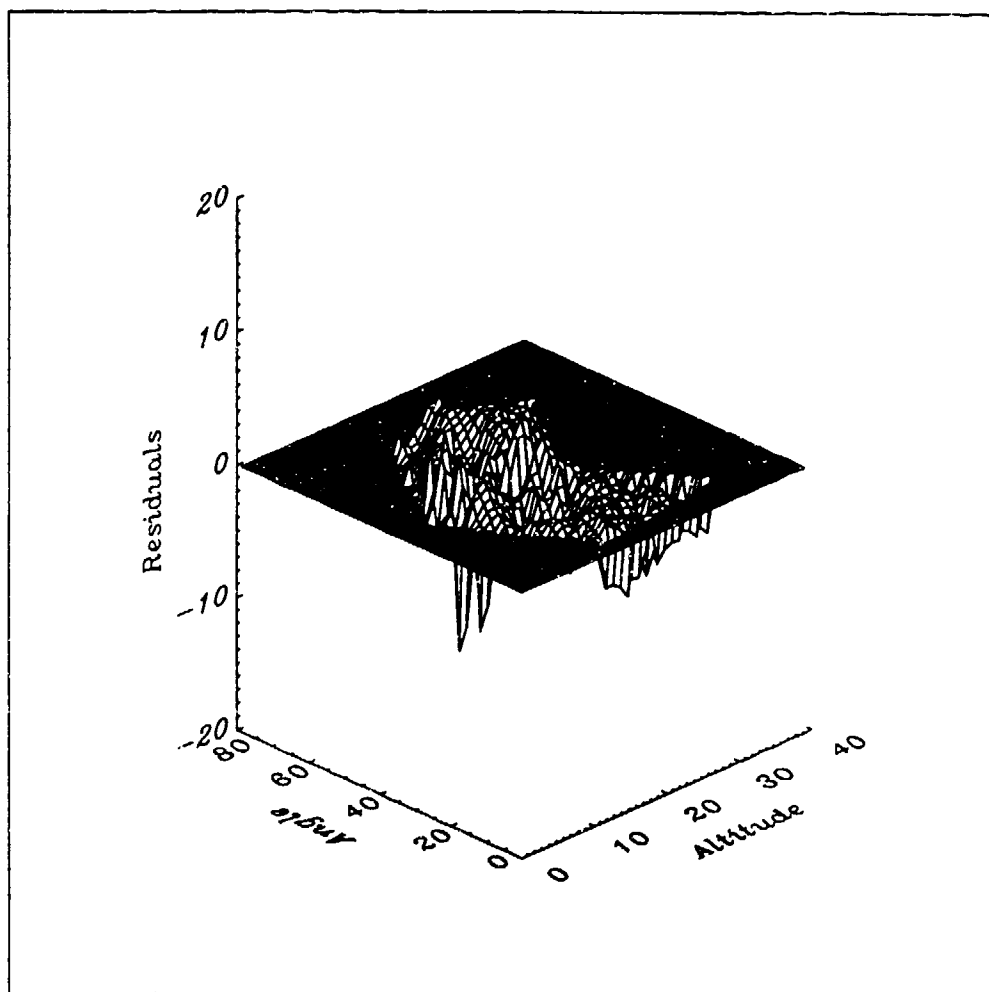
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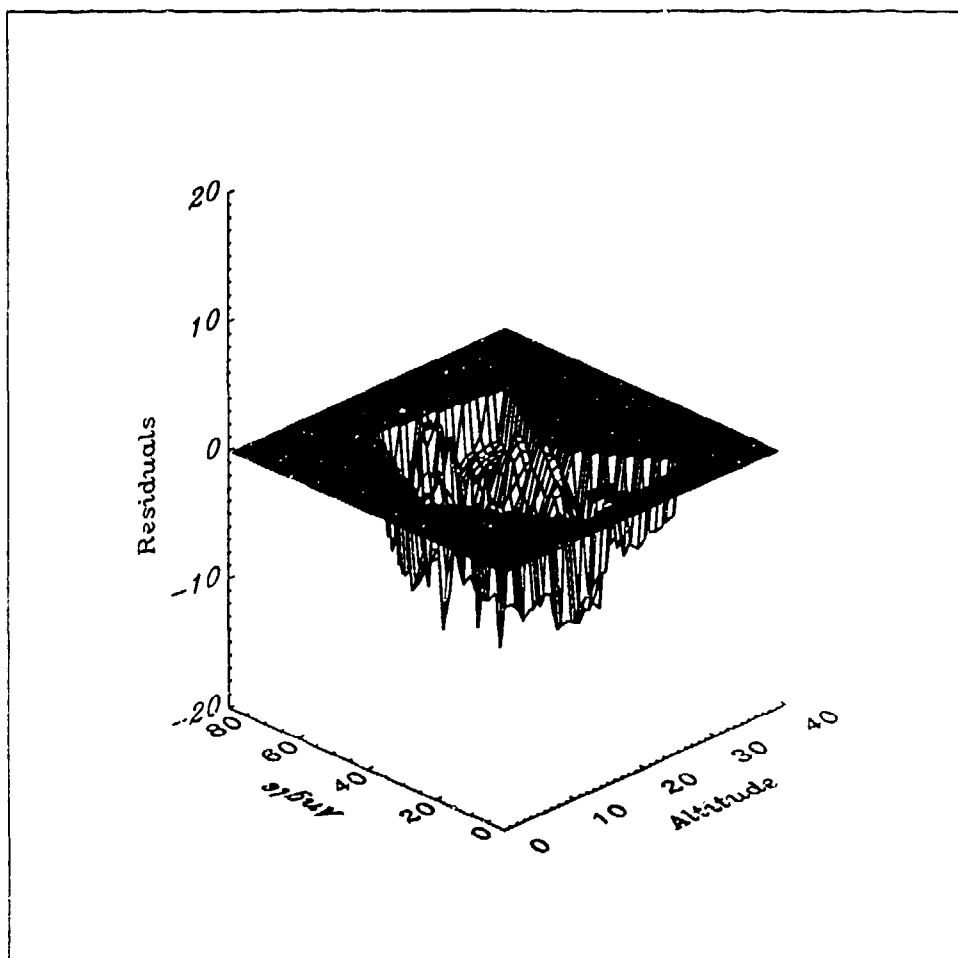
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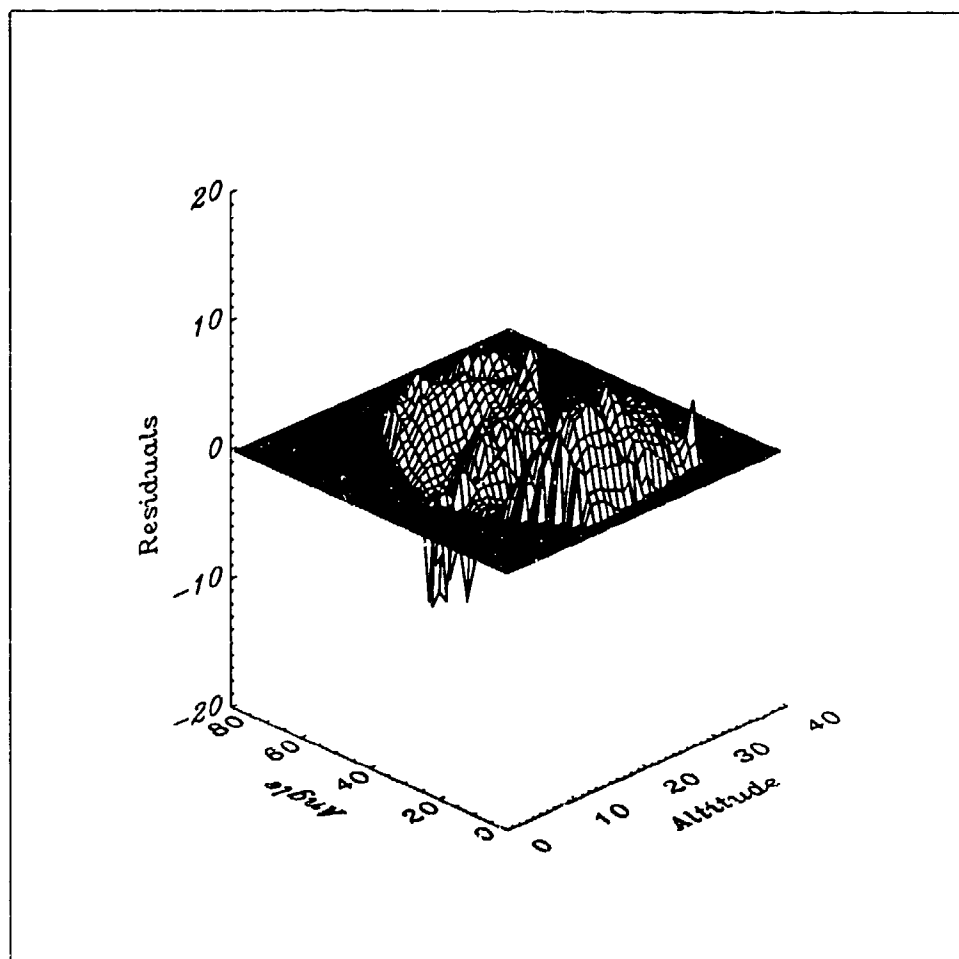
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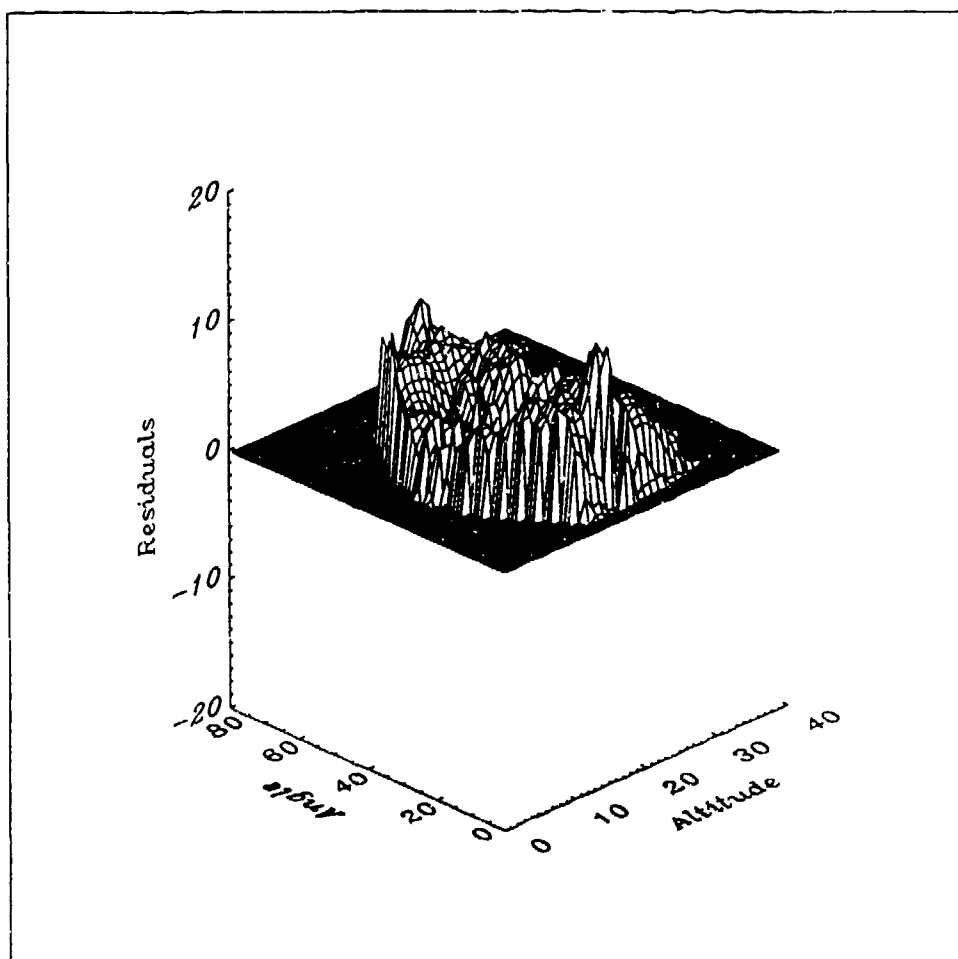
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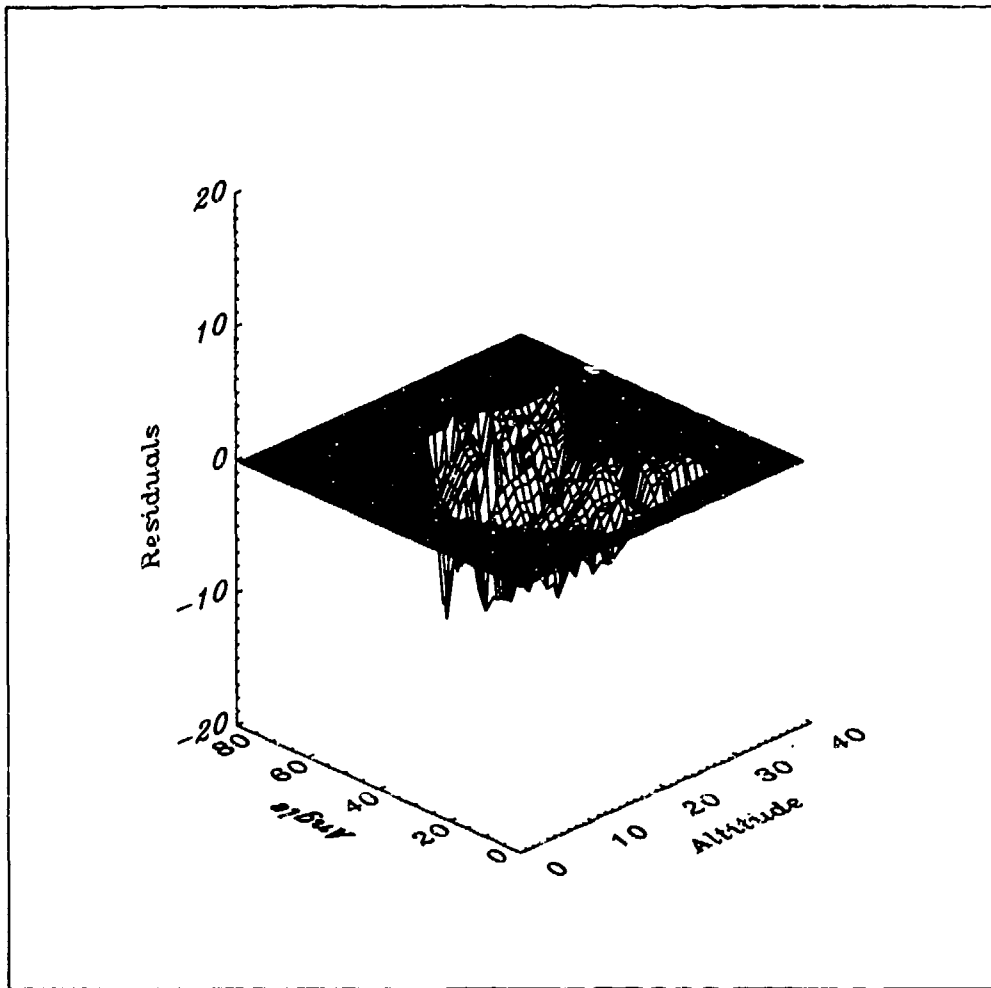
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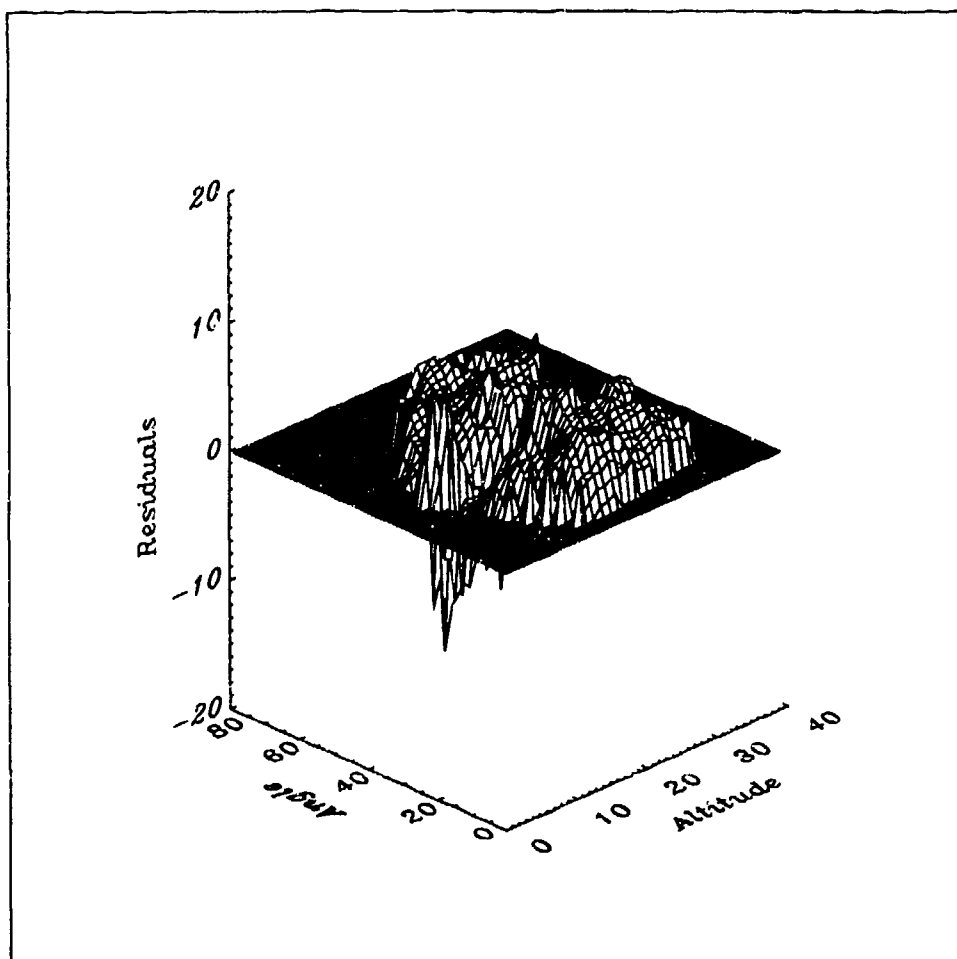
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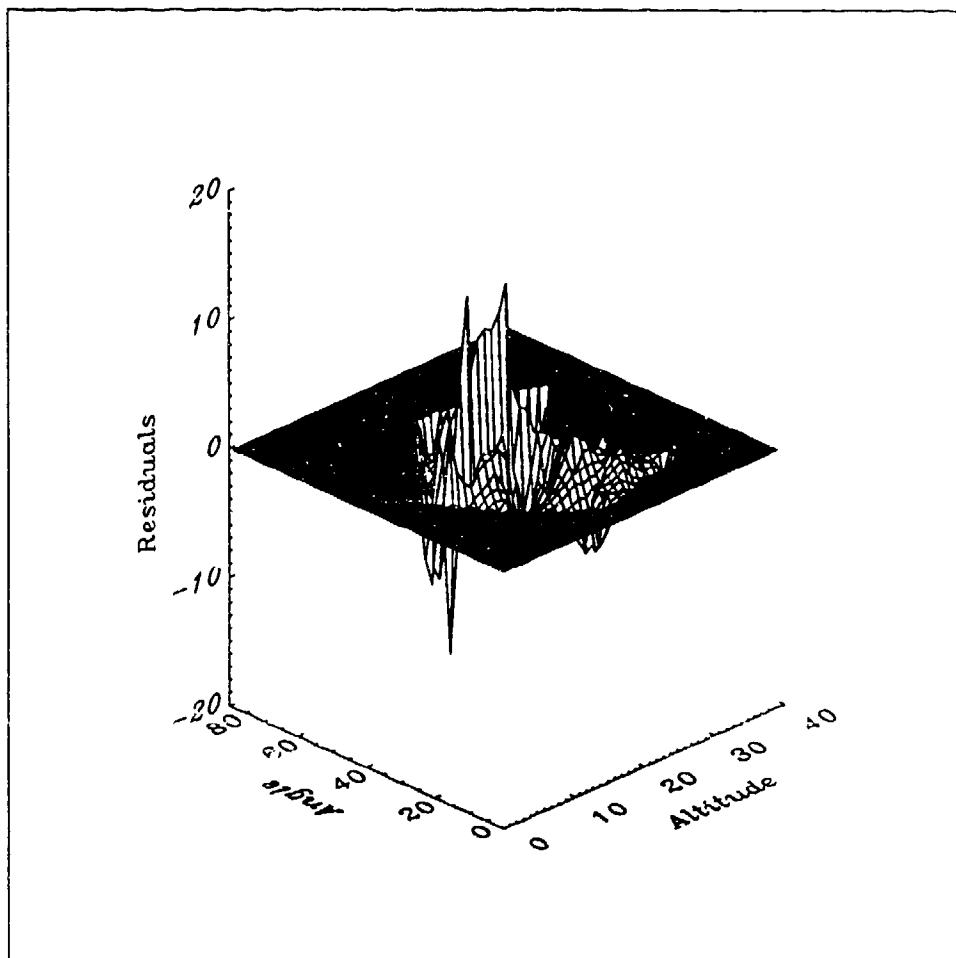
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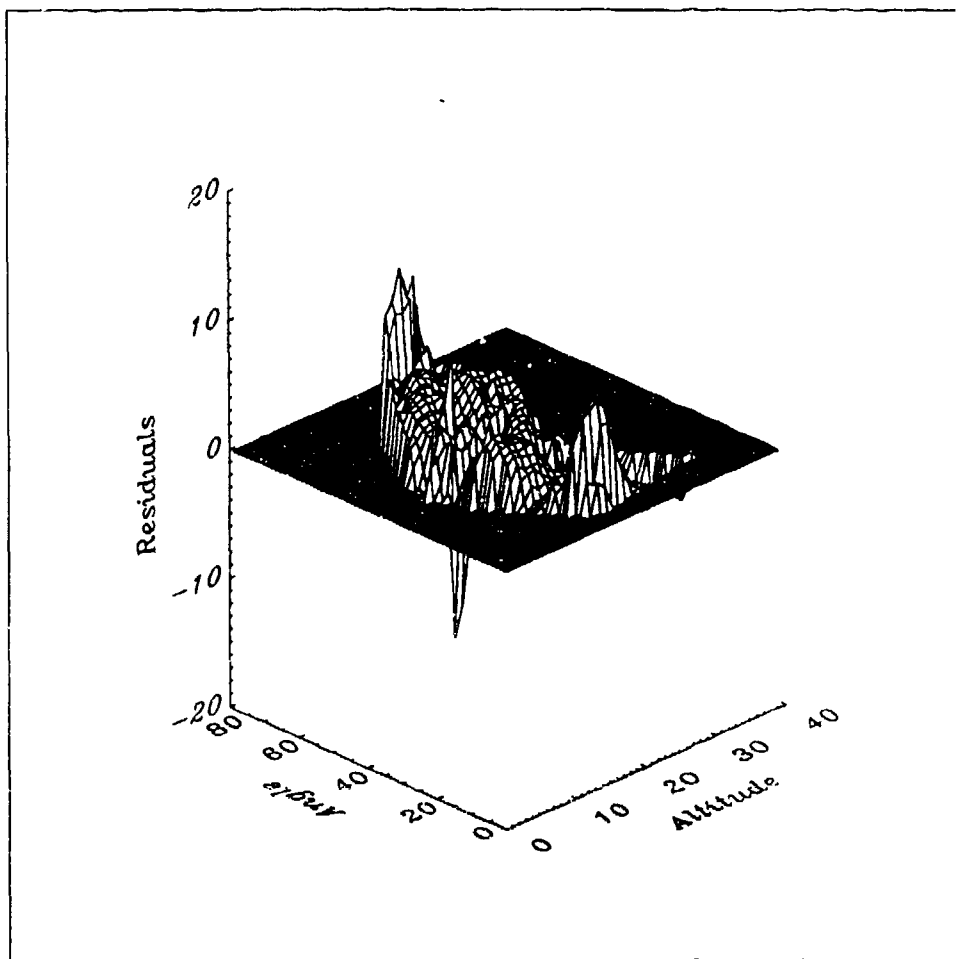
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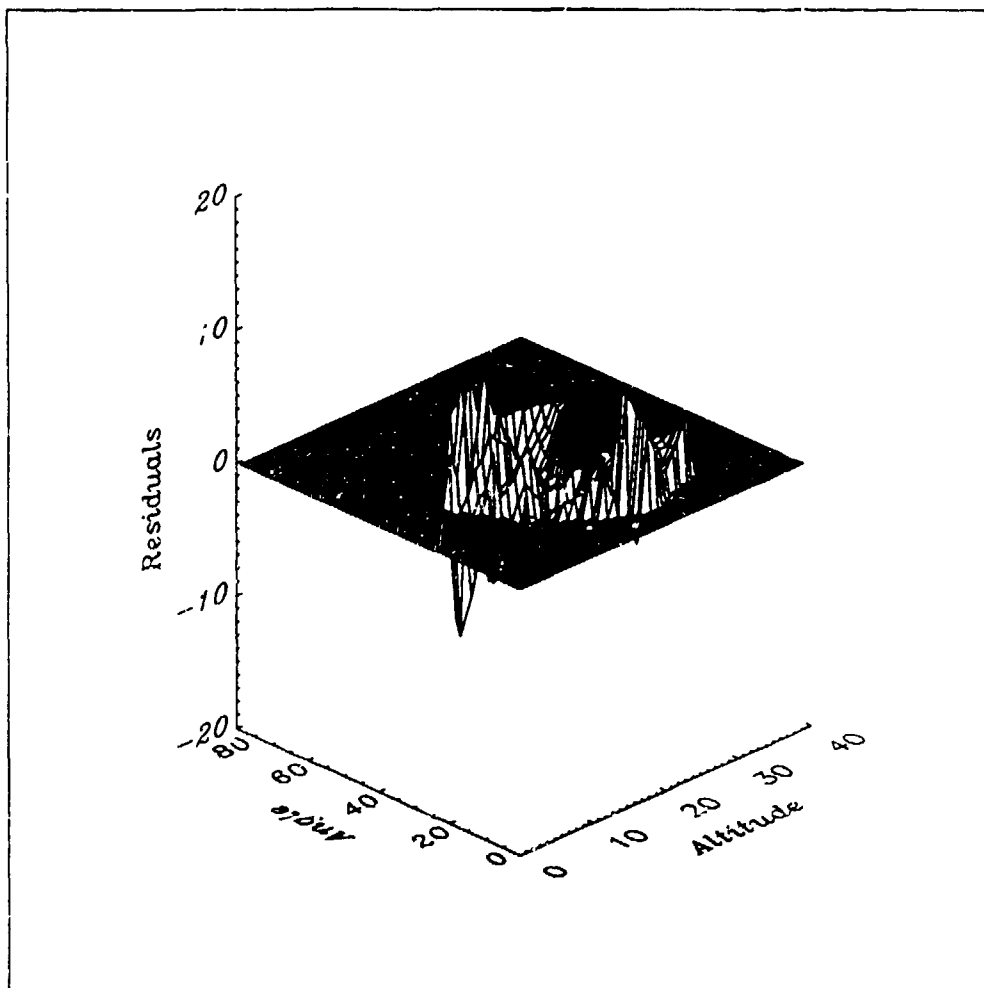
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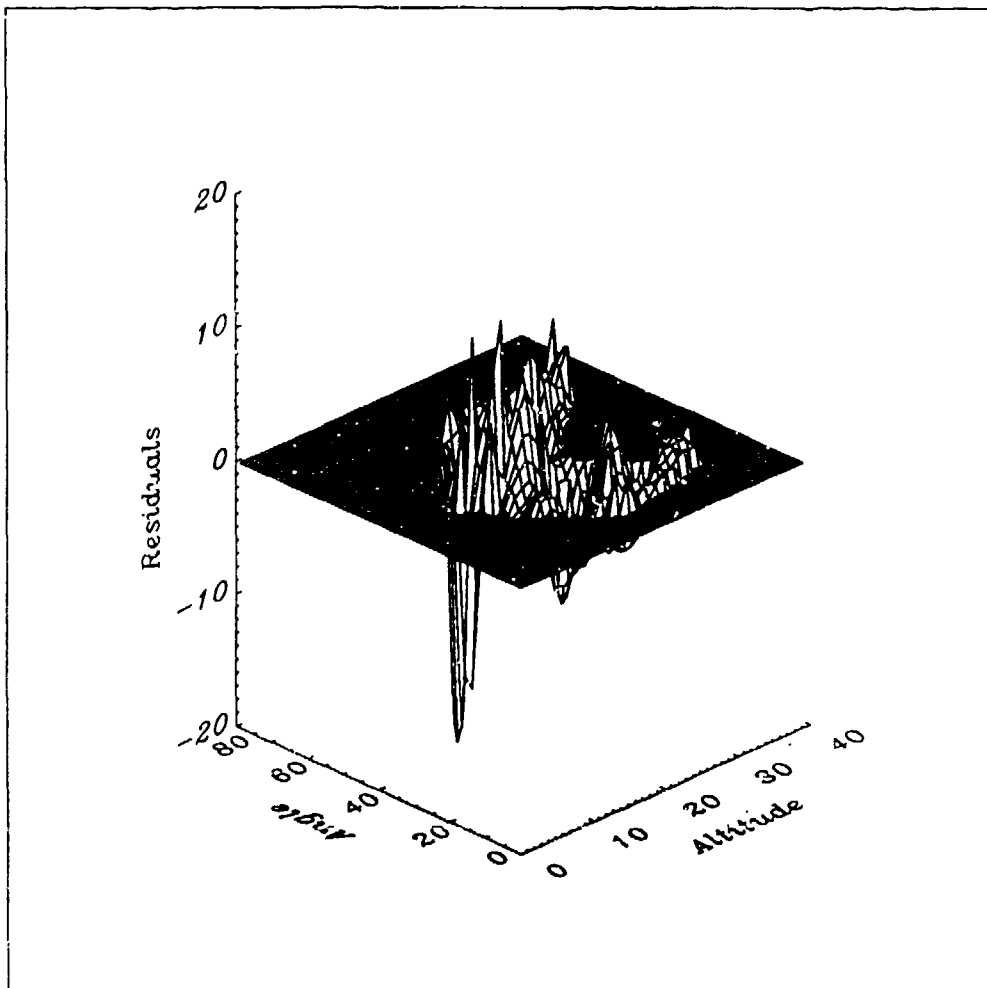
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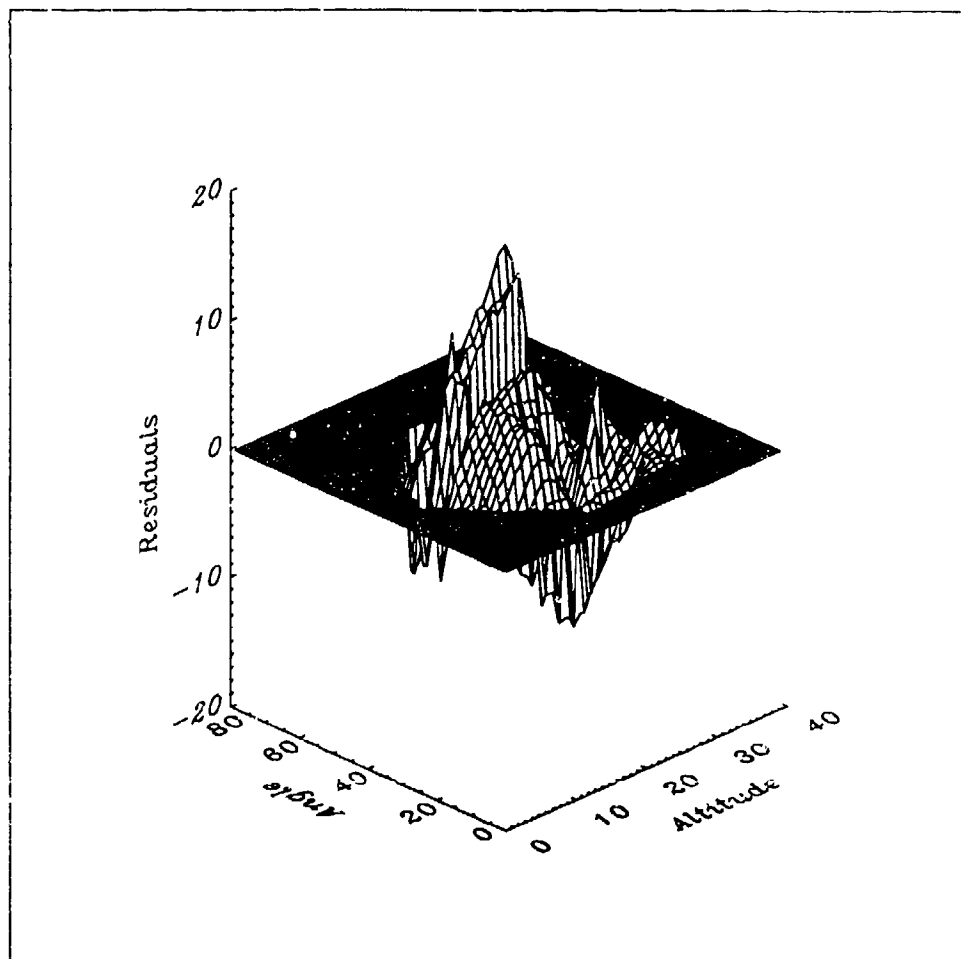
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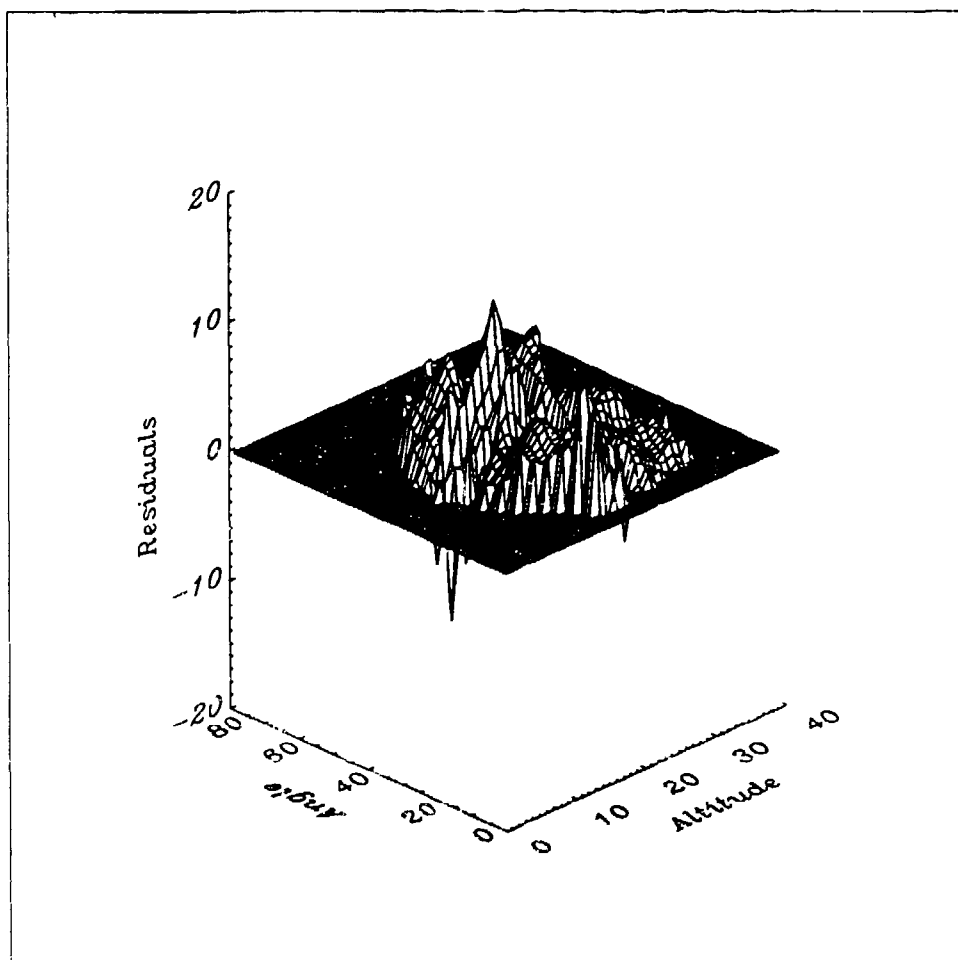
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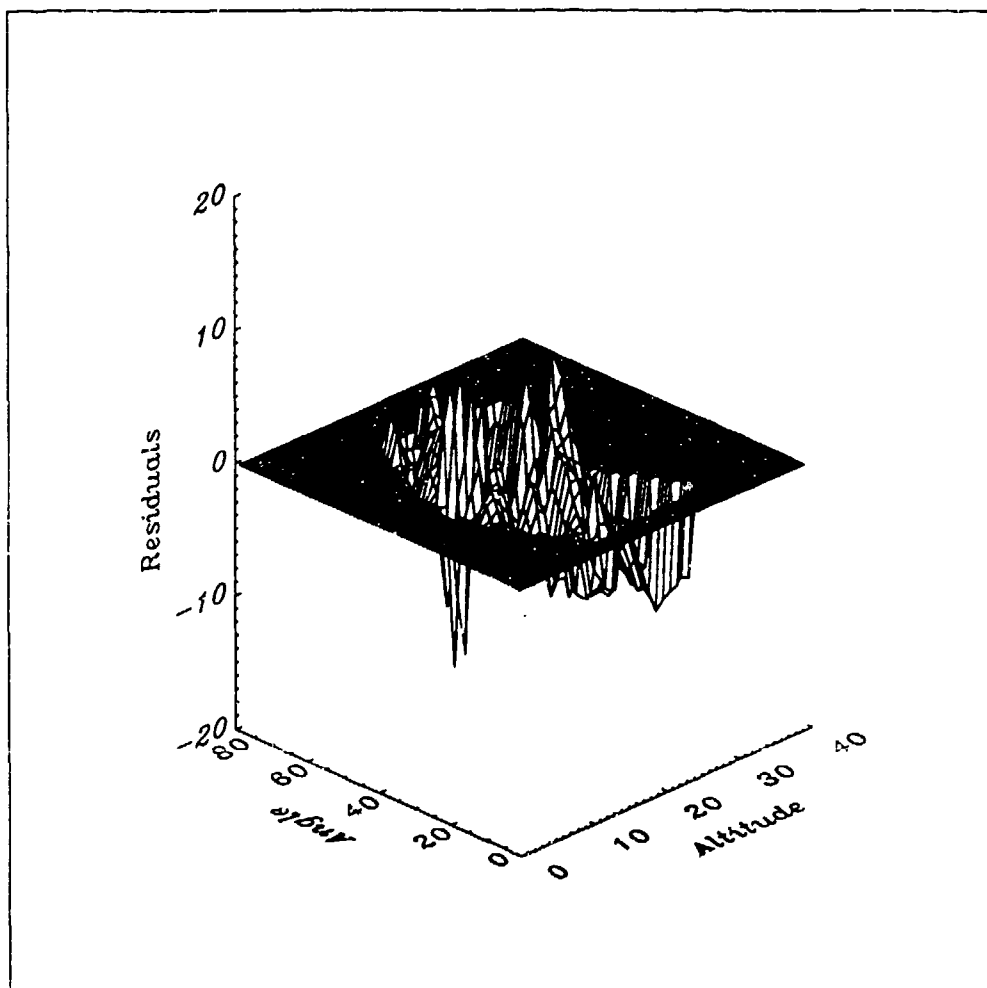
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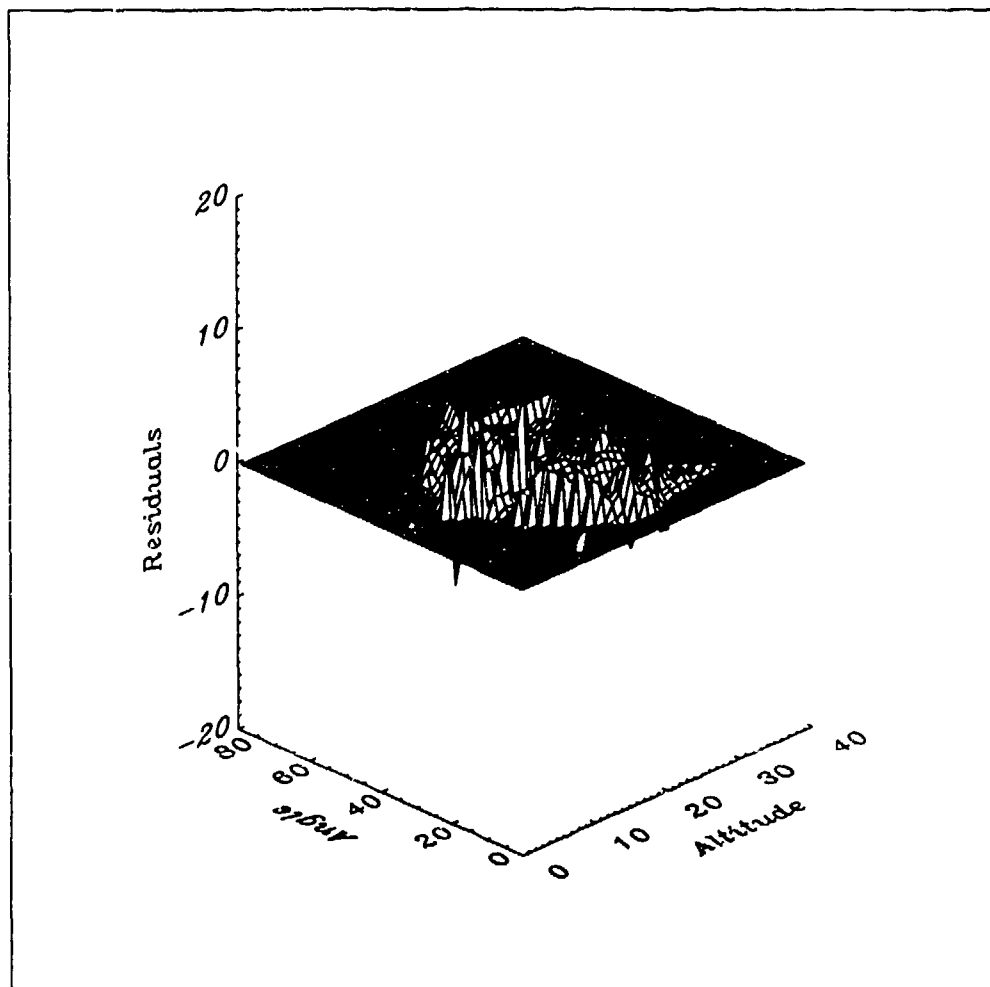
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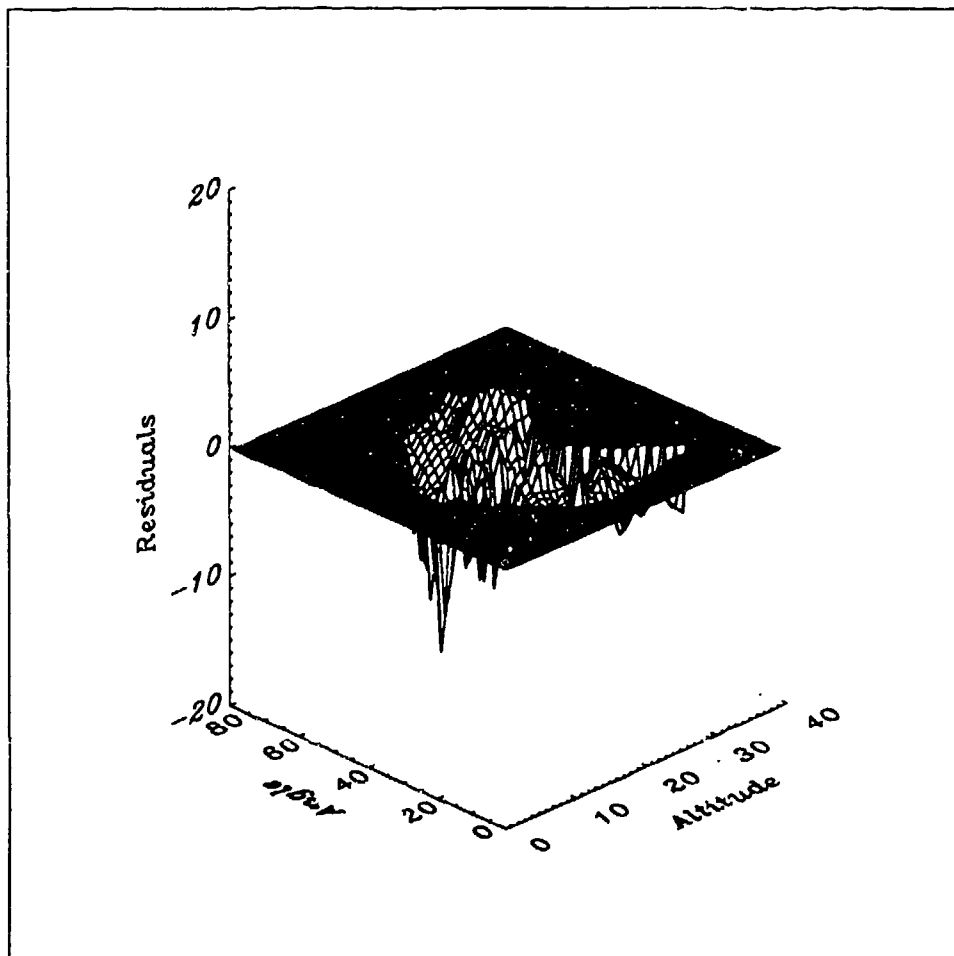
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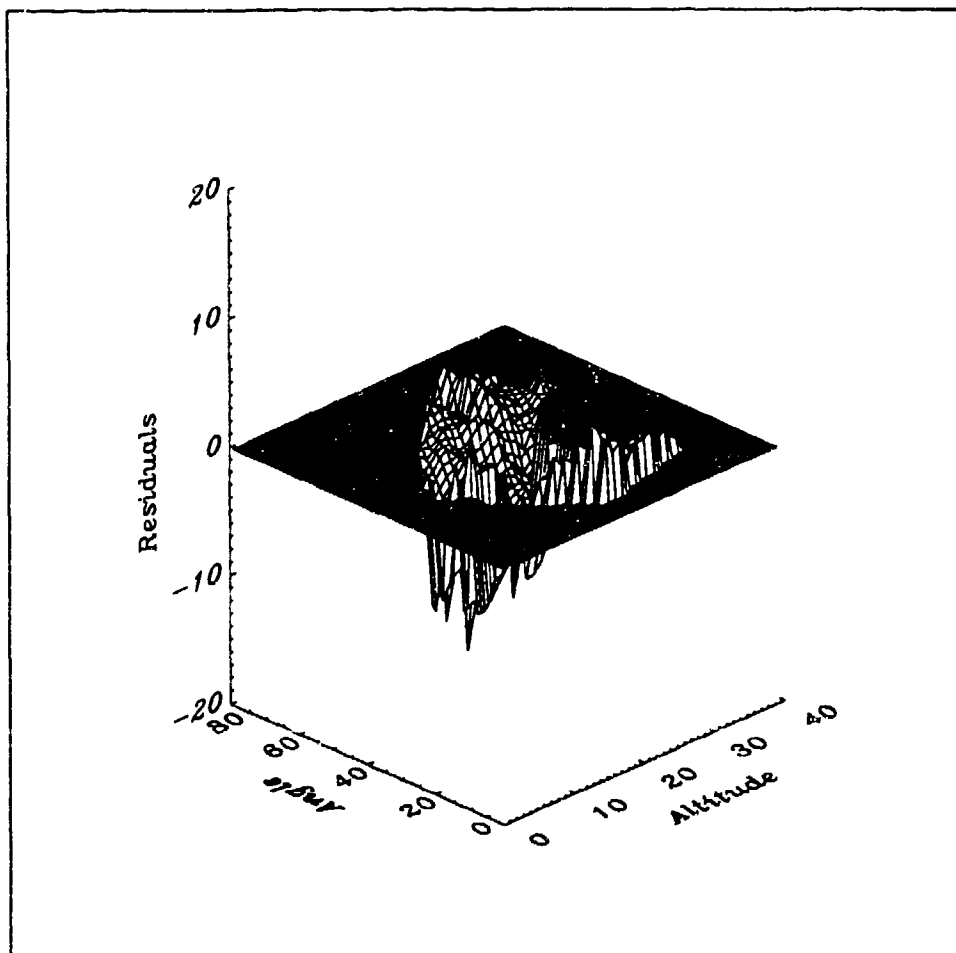
Subject 150 Residuals



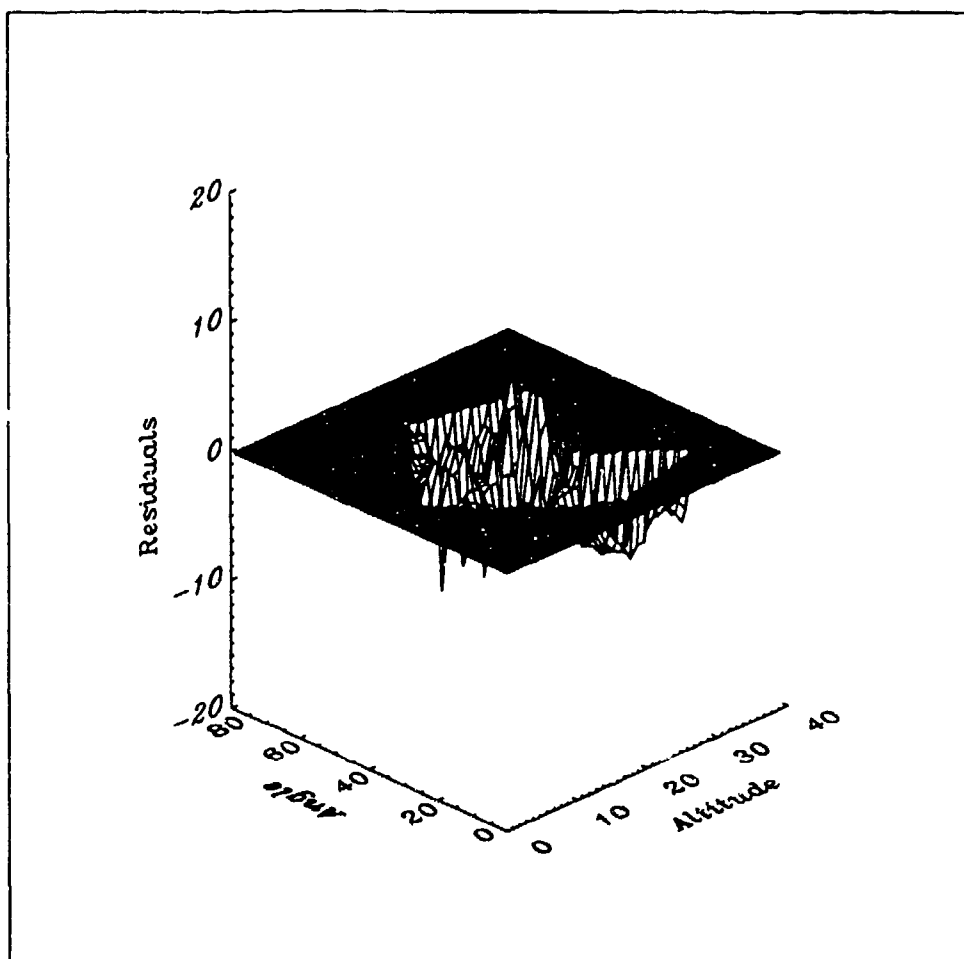
Subject 112 Residuals



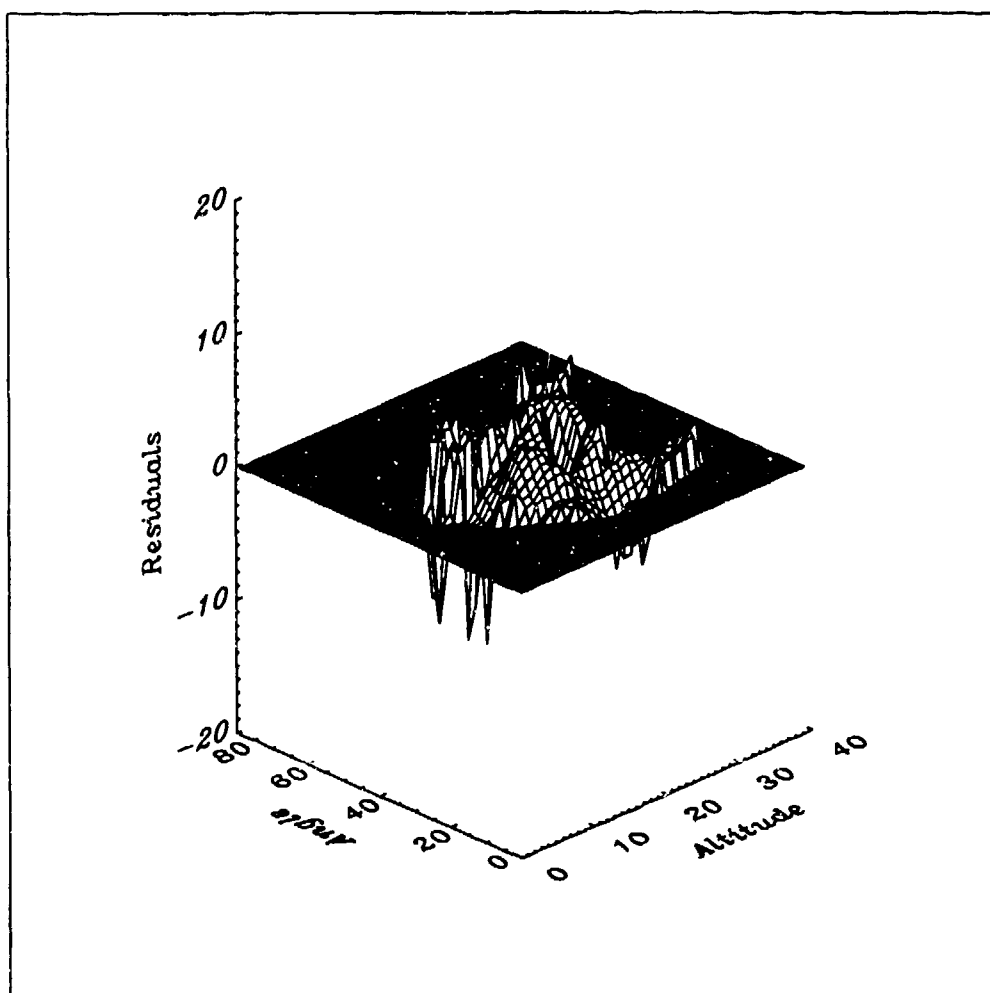
Subject 141 Residuals



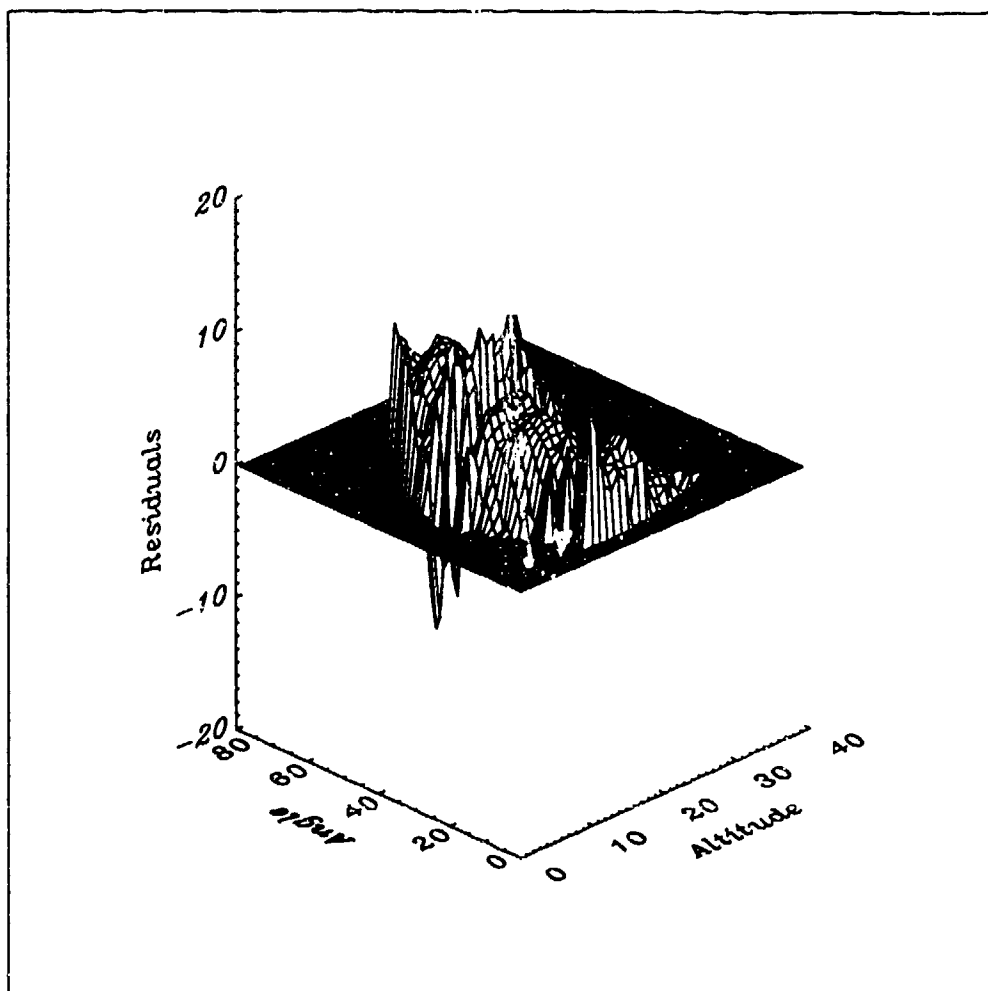
Subject 152 Residuals



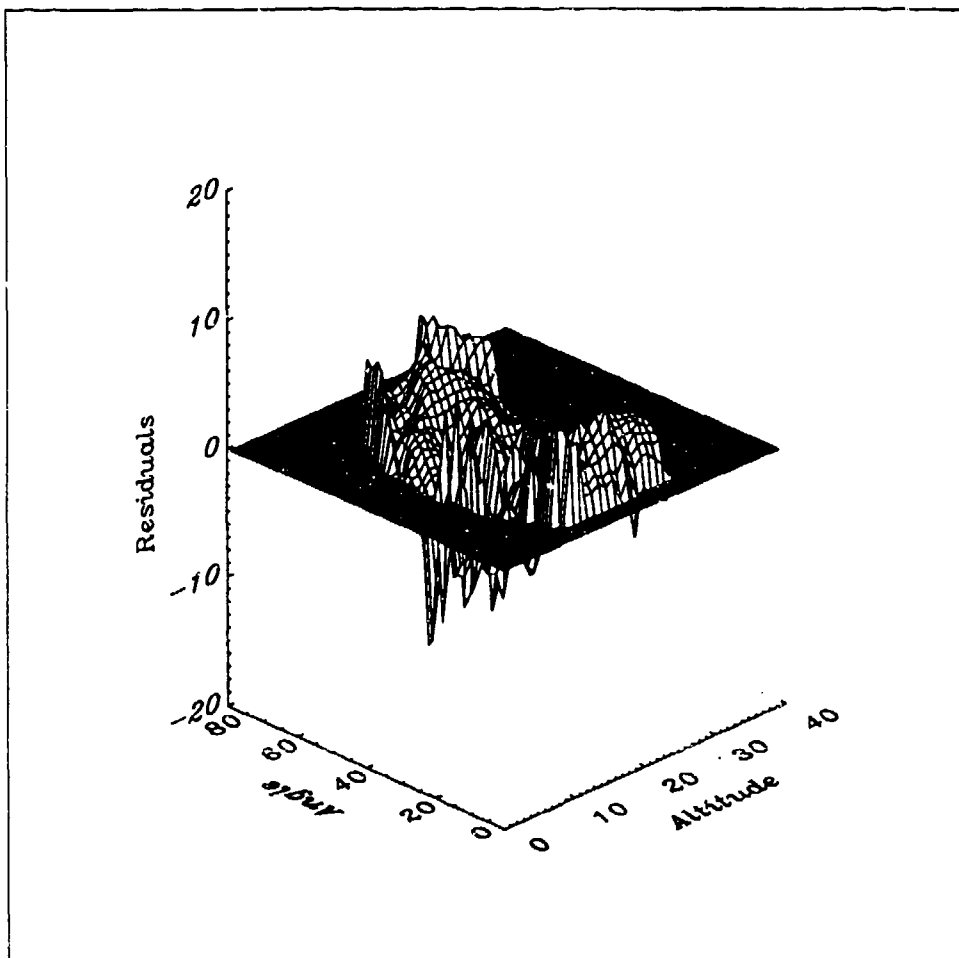
Subject 156 Residuals



Subject 199 Residuals



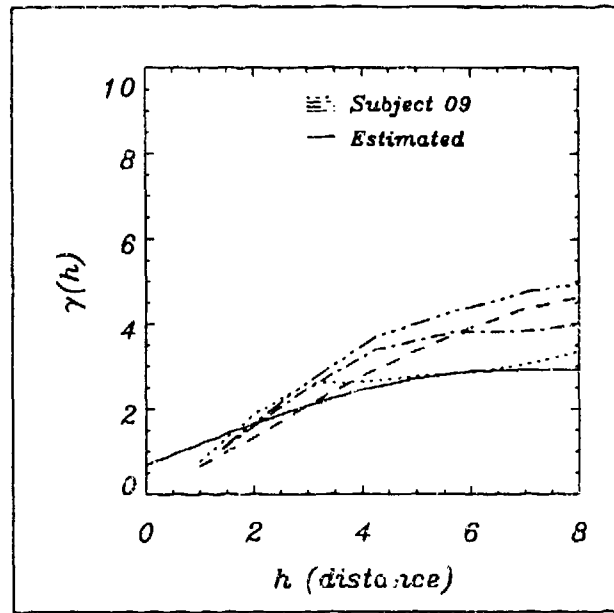
Subject 33 Residuals



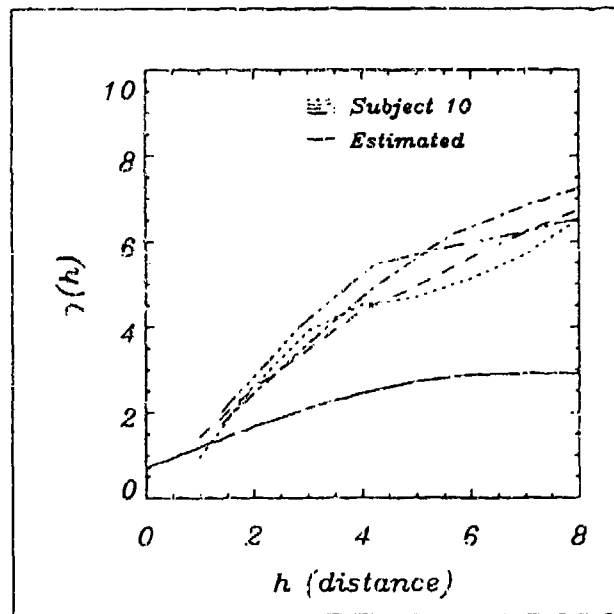
Subject 151 Residuals

## Appendix C. *Variograms*

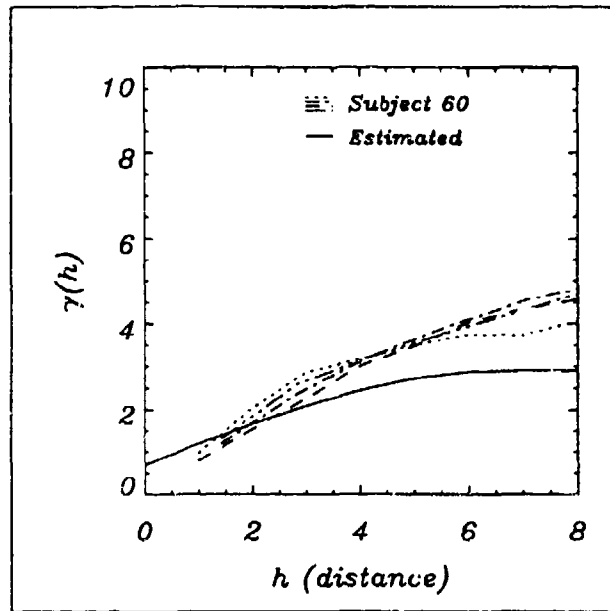
This appendix provides the variograms corresponding to each of the residual data sets in the previous appendix. Each plot displays a set of four variograms (one for each direction for the individual) and the overall variogram.



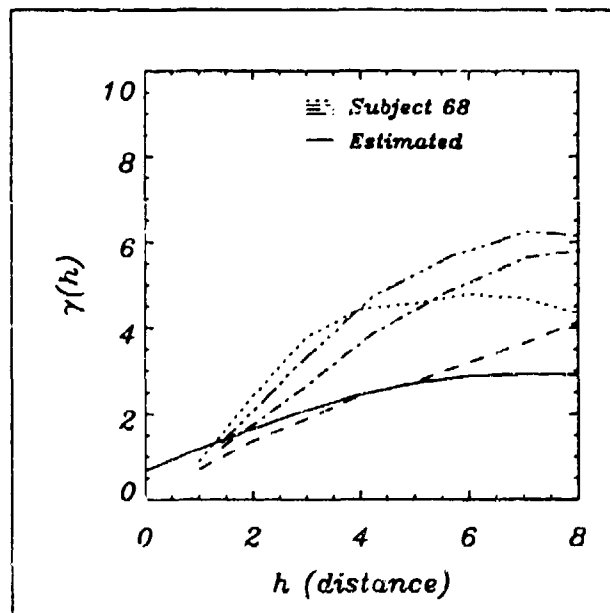
Subject 09 Variograms



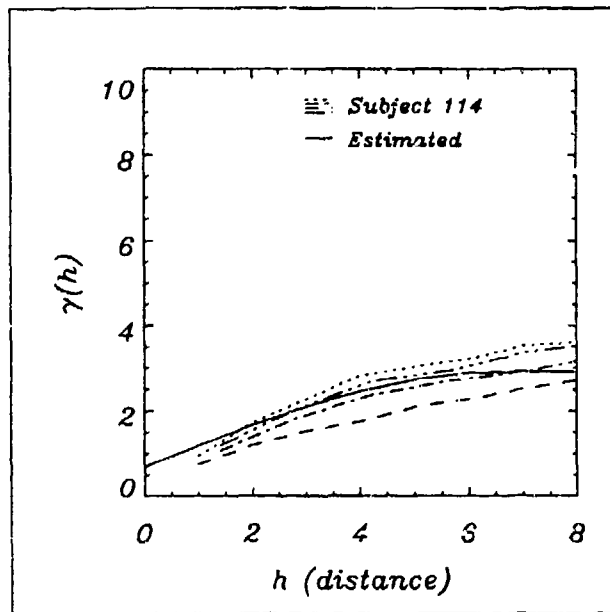
Subject 10 Variograms



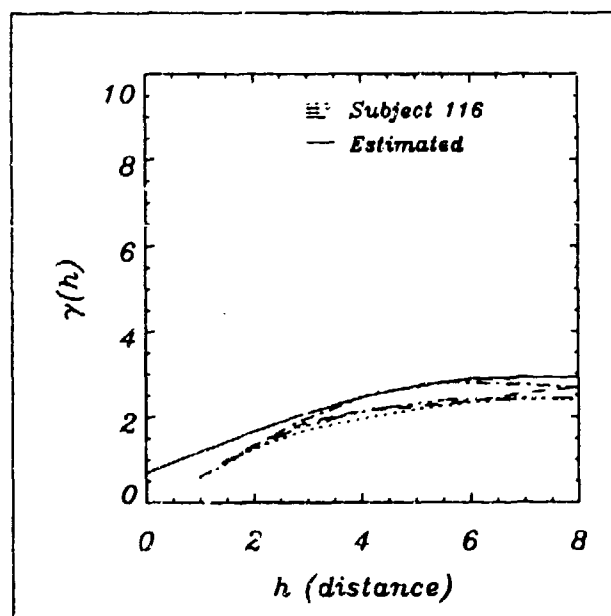
Subject 60 Variograms



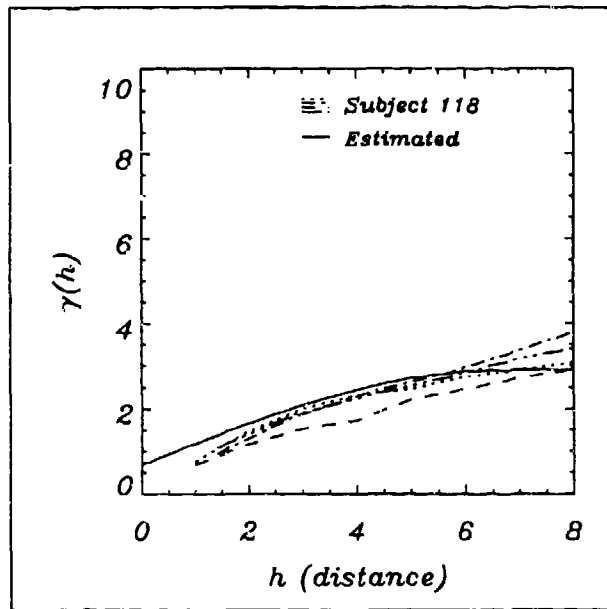
Subject 68 Variograms



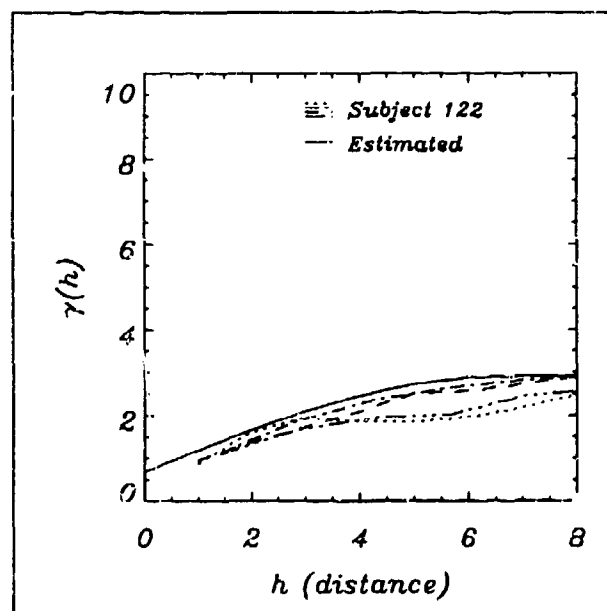
Subject 114 Variograms



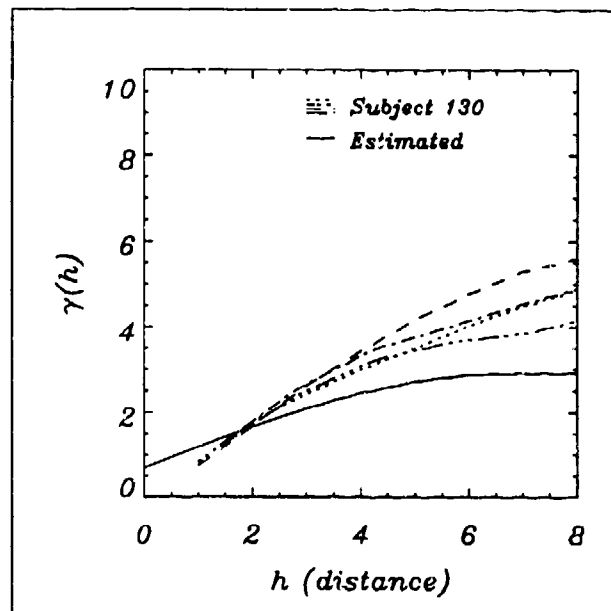
Subject 116 Variograms



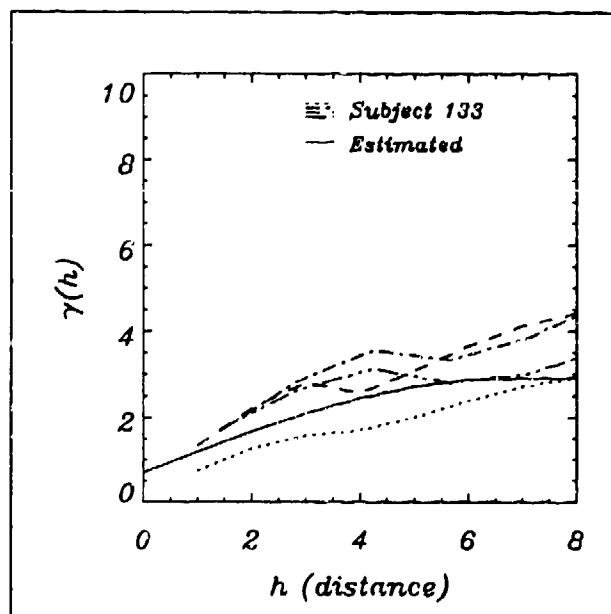
Subject 118 Variograms



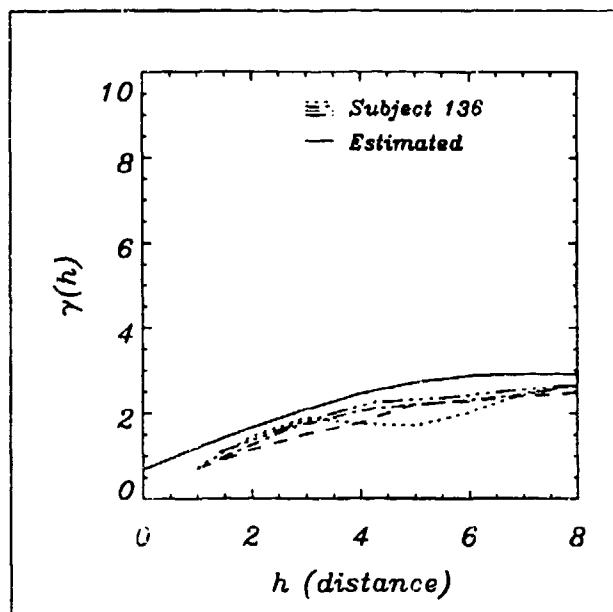
Subject 122 Variograms



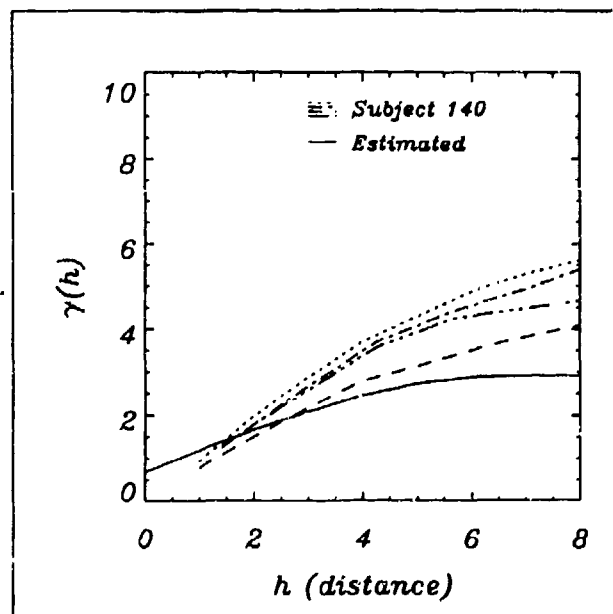
Subject 130 Variograms



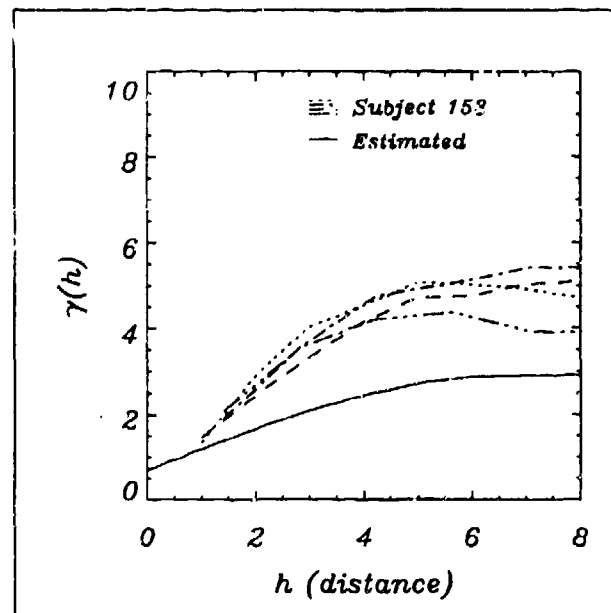
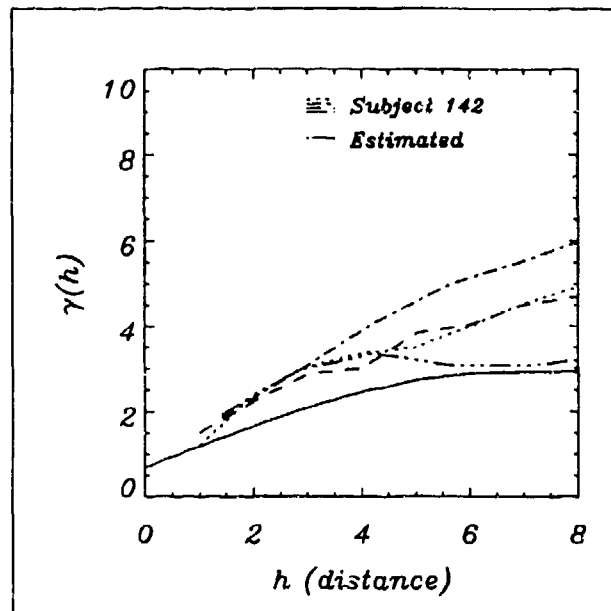
Subject 133 Variograms

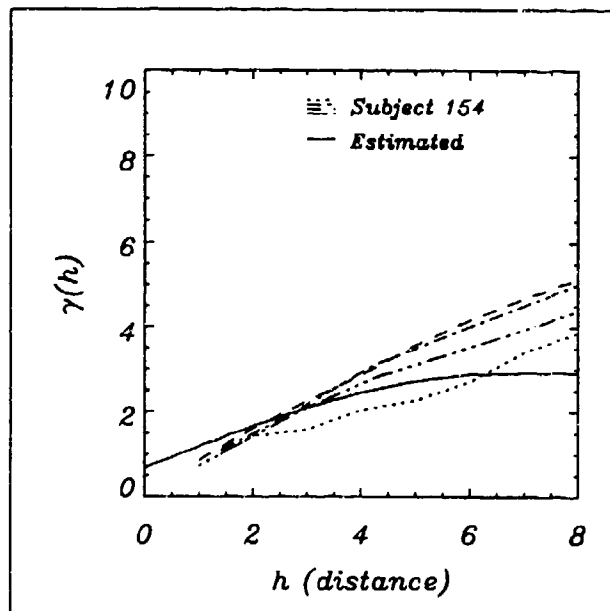


Subject 136 Variograms

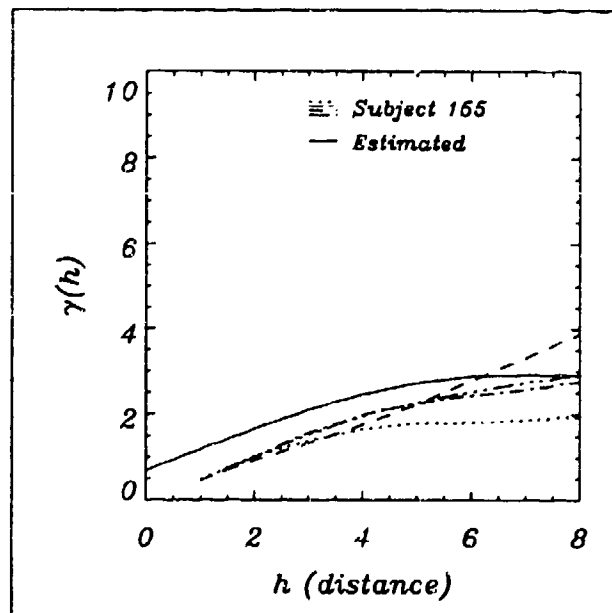


Subject 140 Variograms

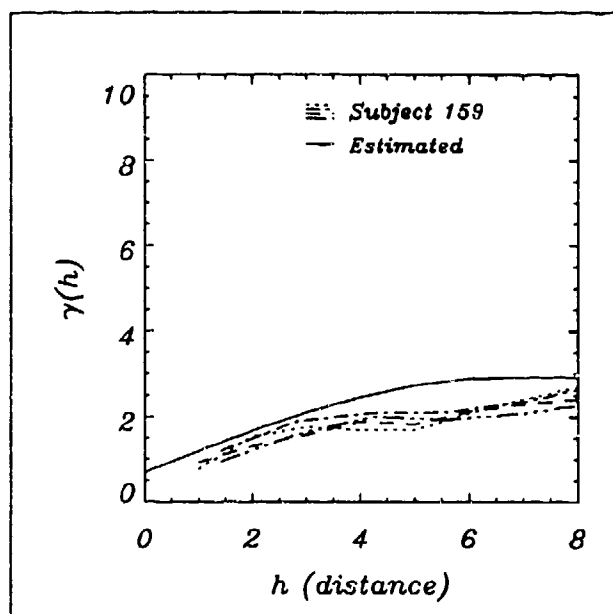




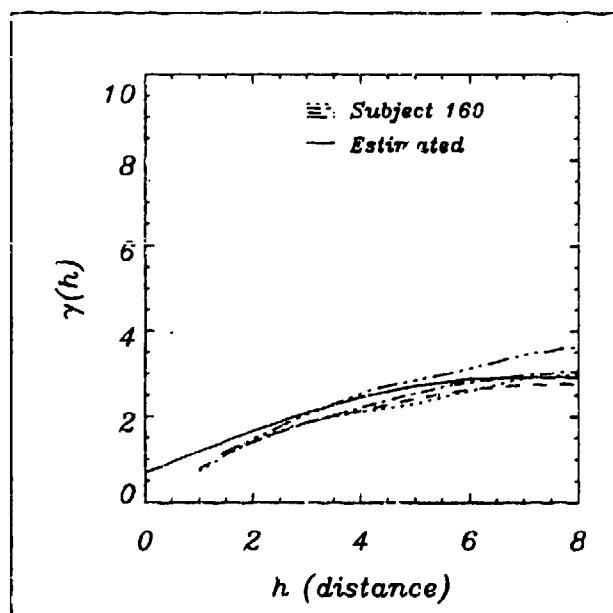
Subject 154 Variograms



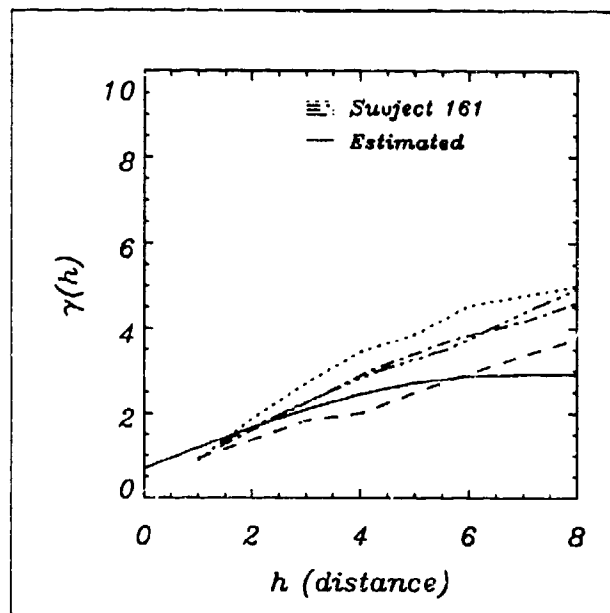
Subject 155 Variograms



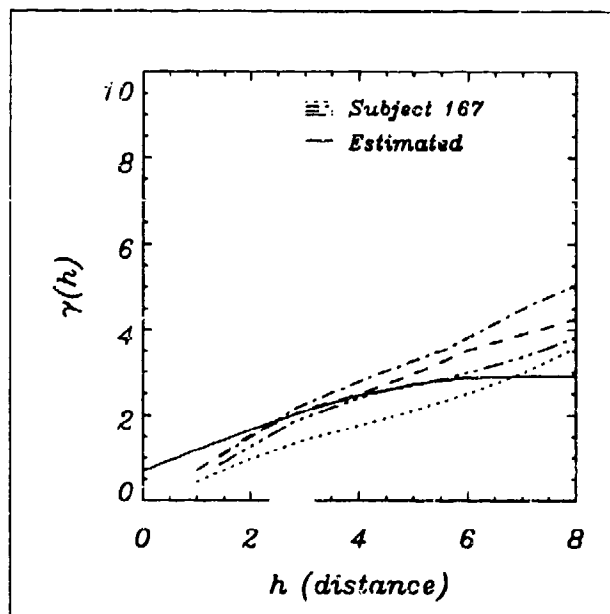
Subject 159 Variograms



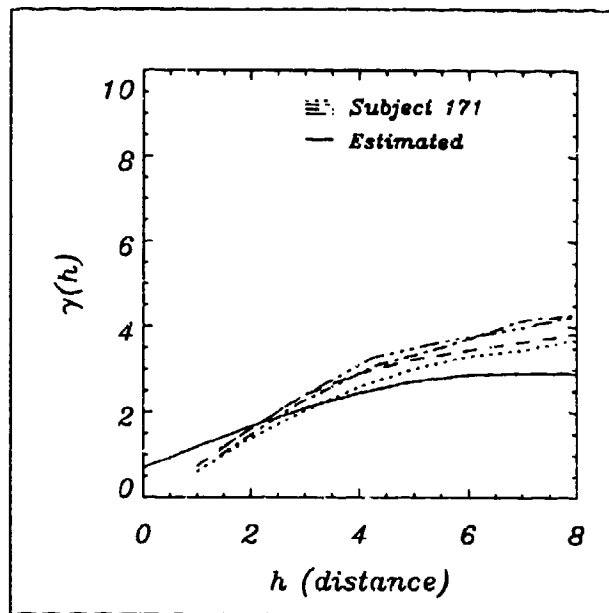
Subject 160 Variograms



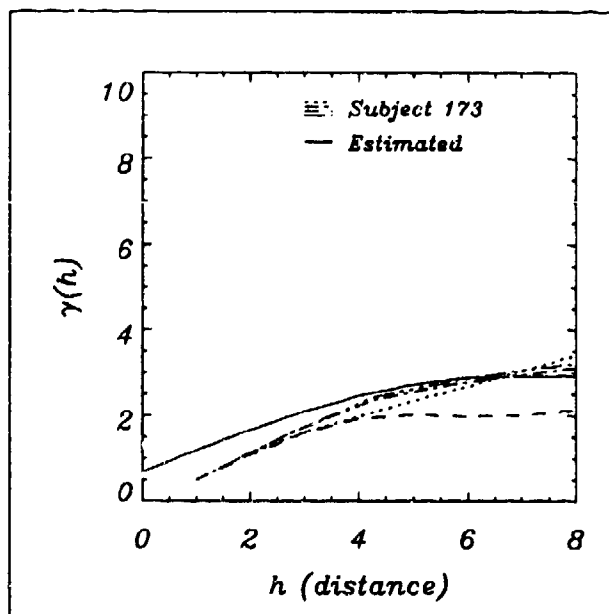
Subject 161 Variograms



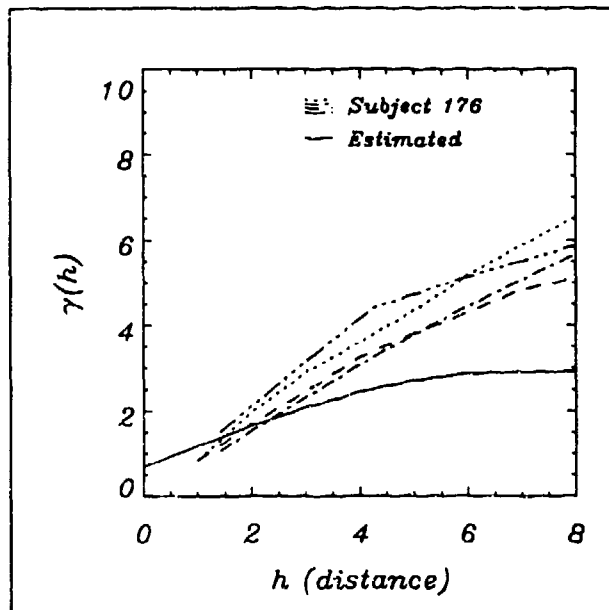
Subject 167 Variograms



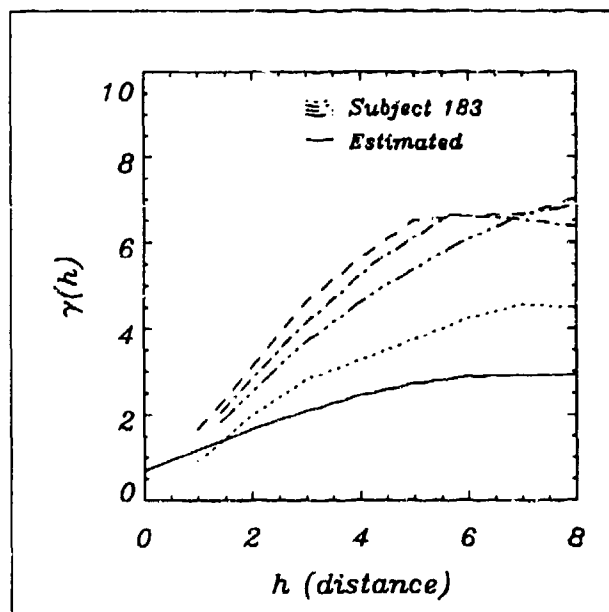
Subject 171 Variograms



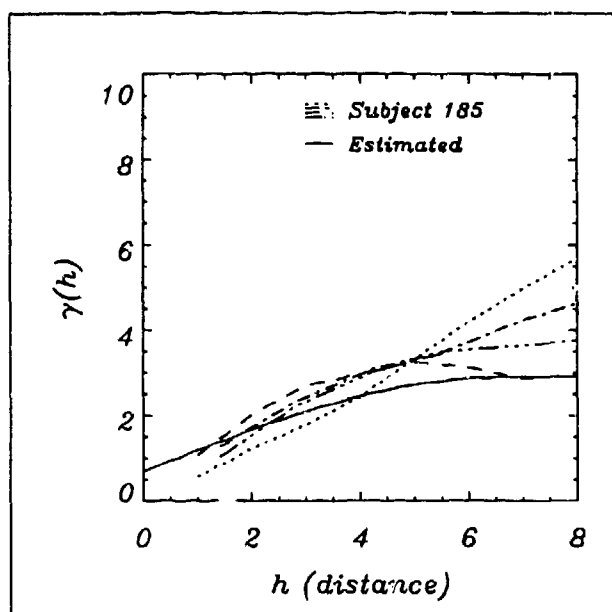
Subject 173 Variograms



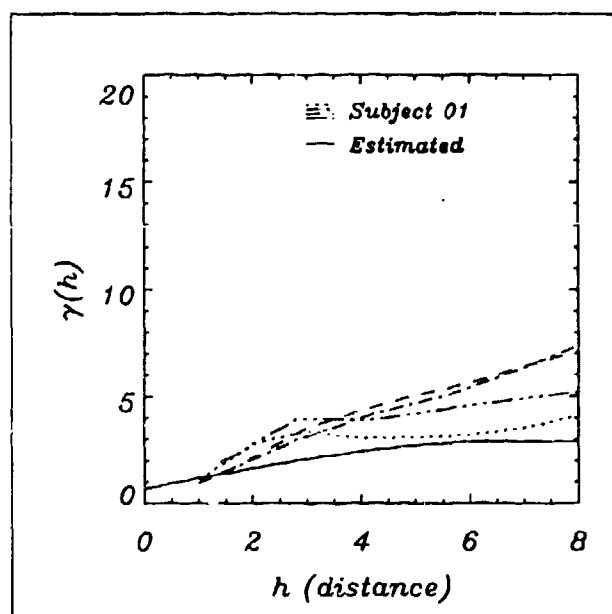
Subject 176 Variograms



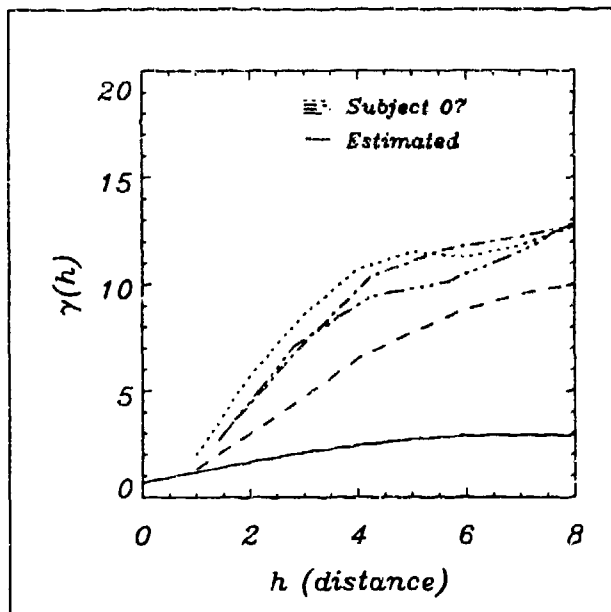
Subject 183 Variograms



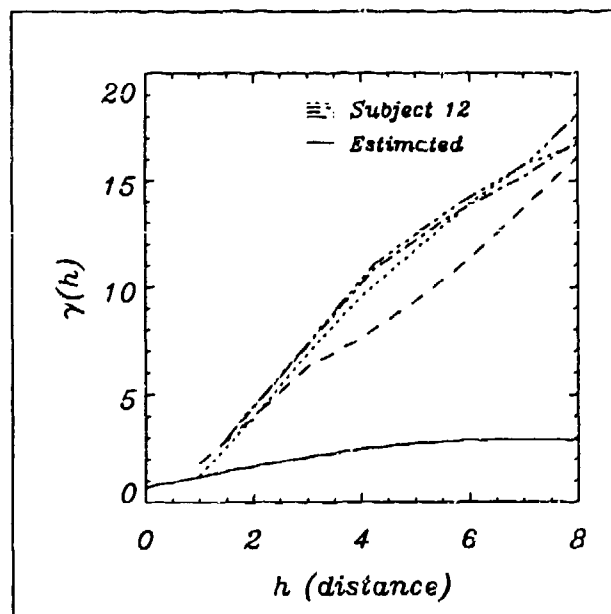
Subject 185 Variograms



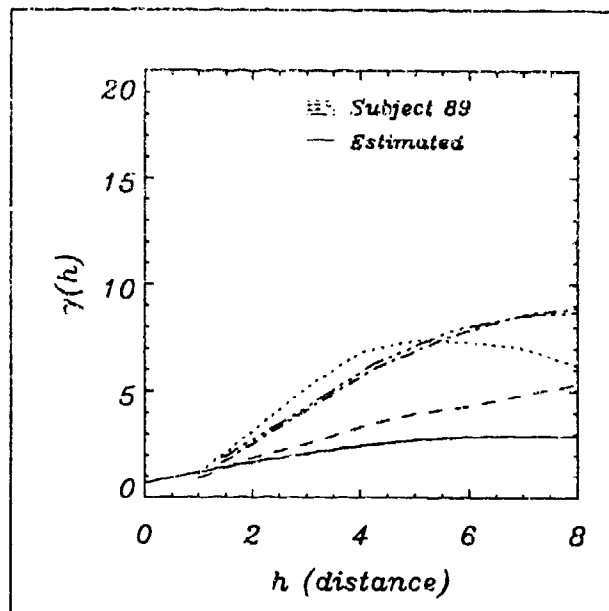
Subject 01 Variograms



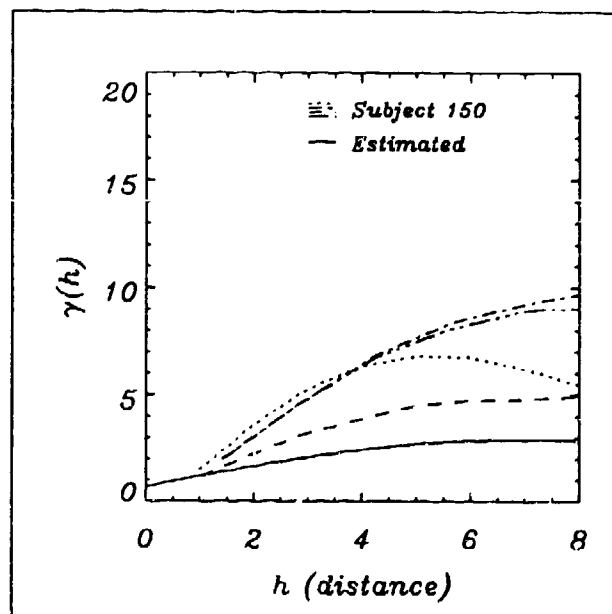
Subject 07 Variograms



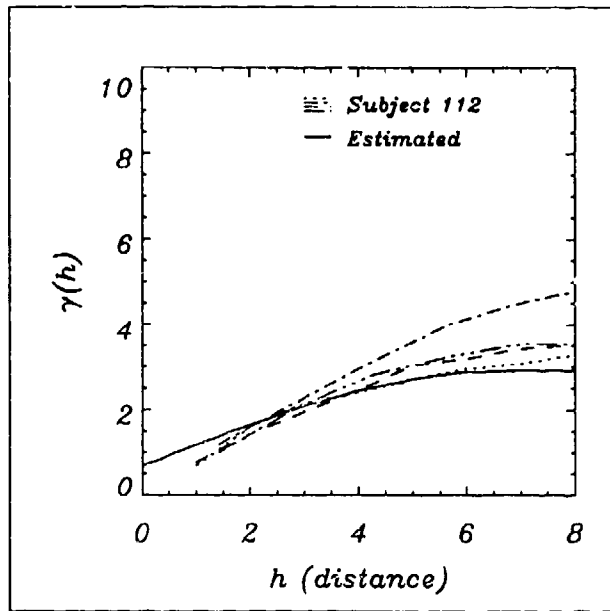
Subject 12 Variograms



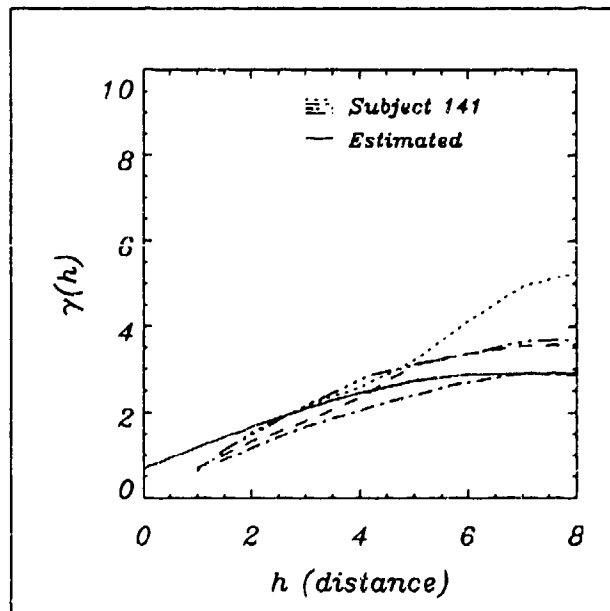
Subject 89 Variograms



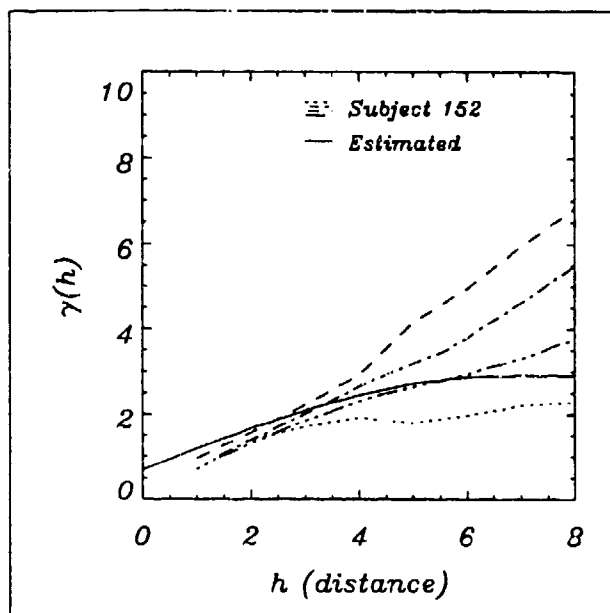
Subject 150 Variograms



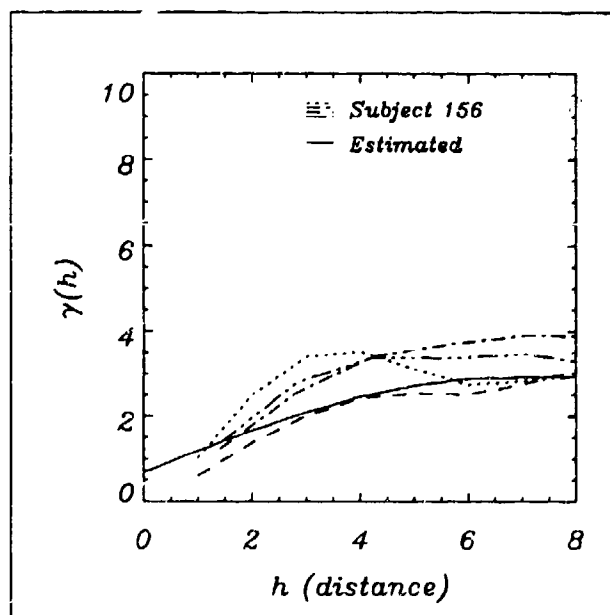
Subject 112 Variograms



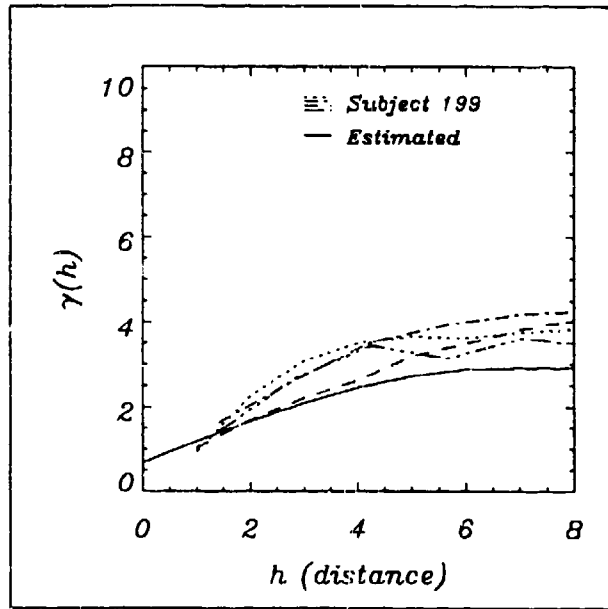
Subject 141 Variograms



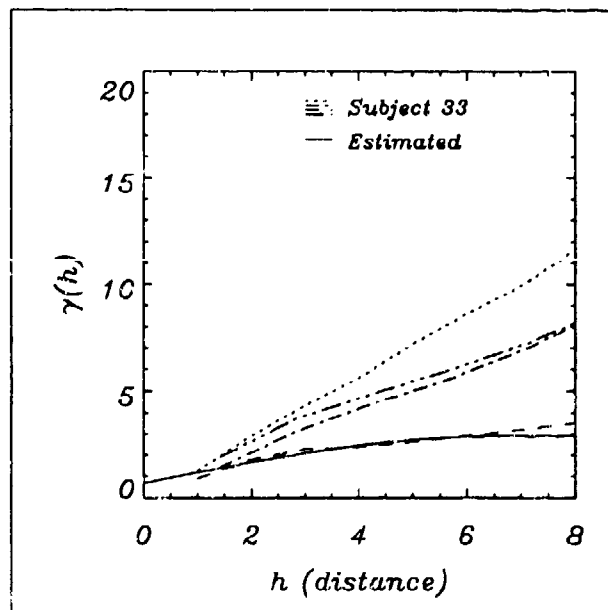
Subject 152 Variograms



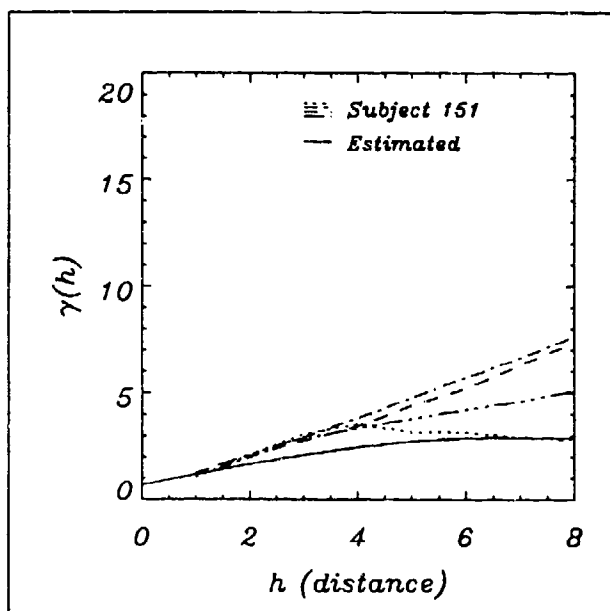
Subject 156 Variograms



Subject 199 Variograms



Subject 33 Variograms

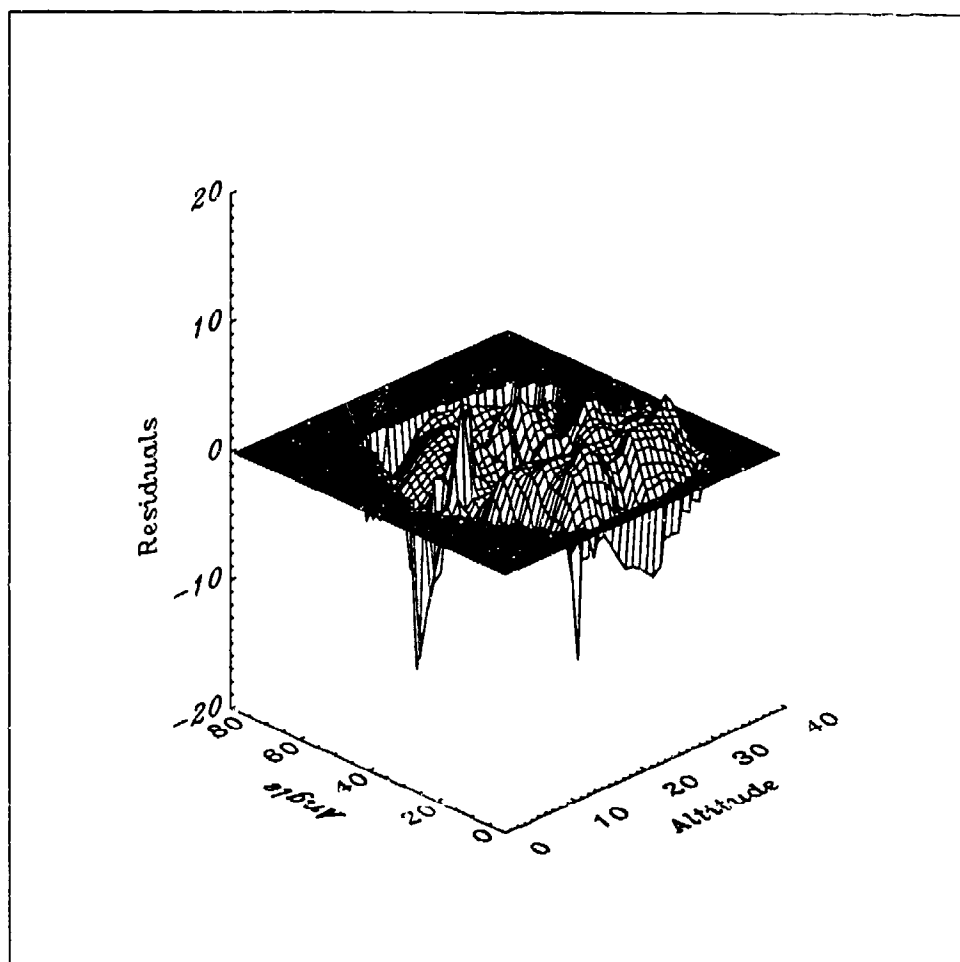


Subject 151 Variograms

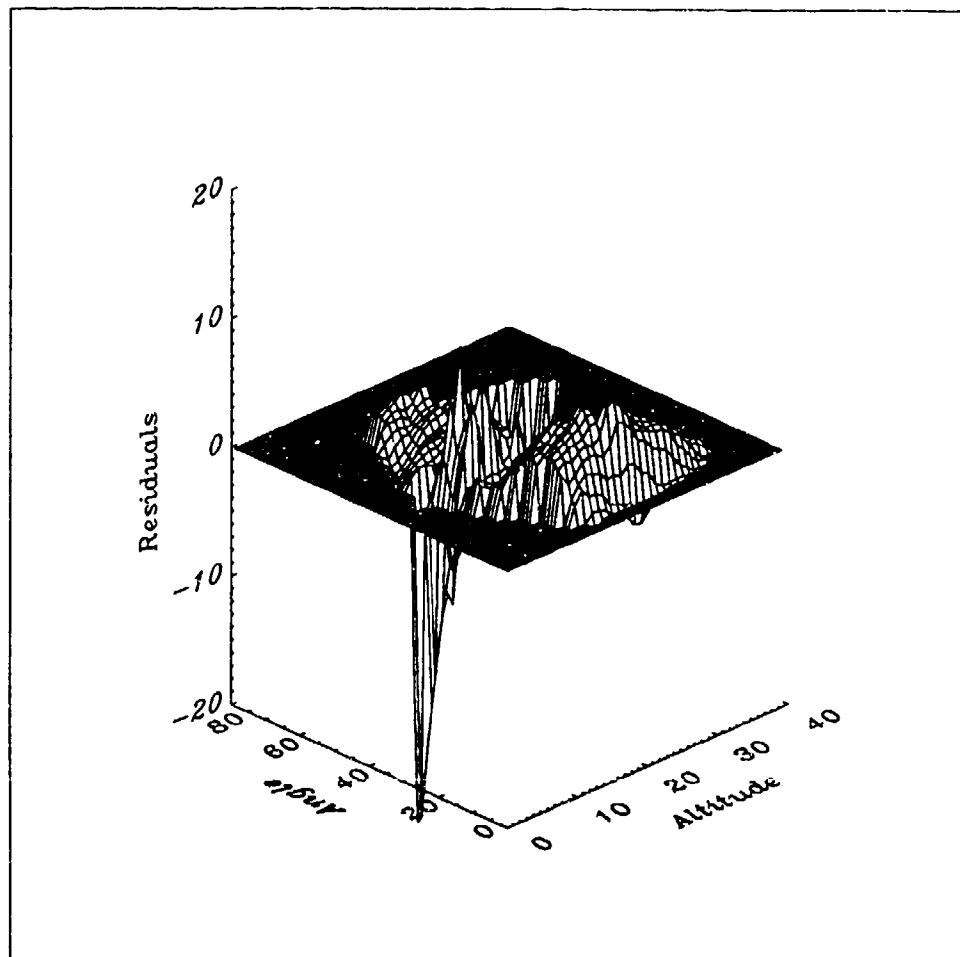
## Appendix D. *Kriging Analysis Figures*

### *Kriged Residual Plots*

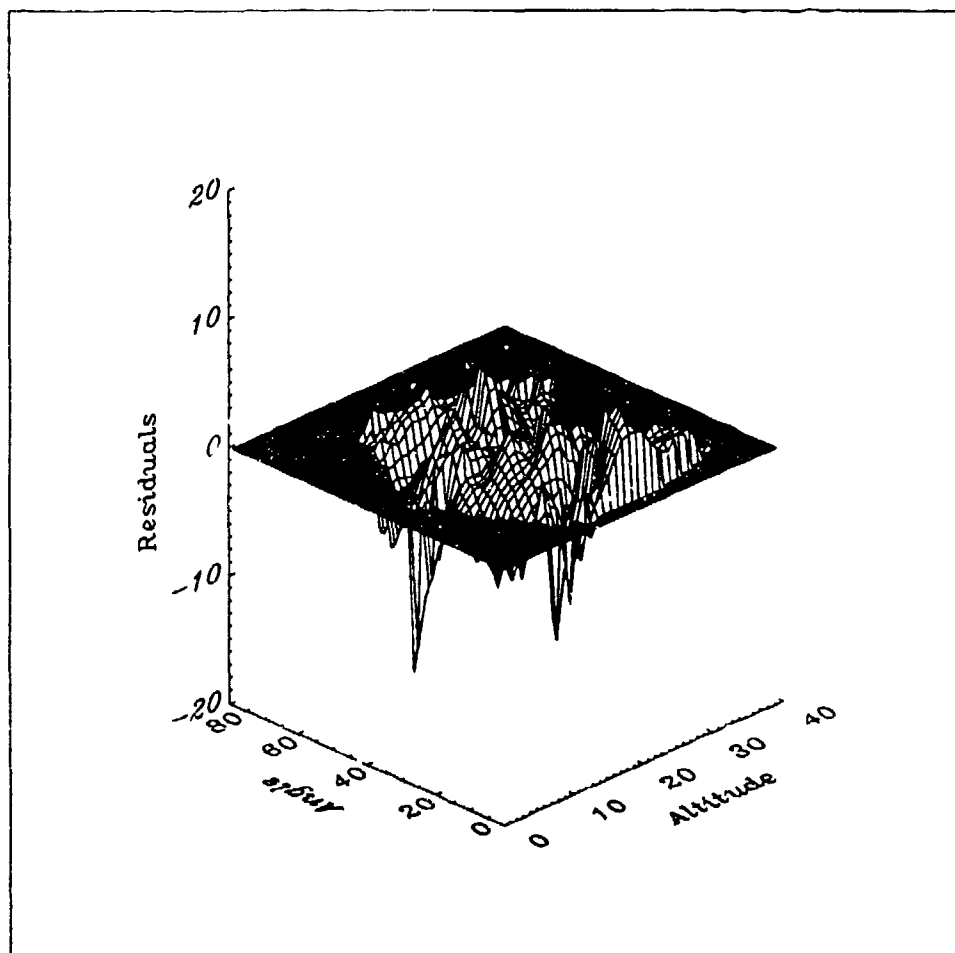
This section includes the kriged residual plots for the 30 data sets used in kriging and updating procedures.



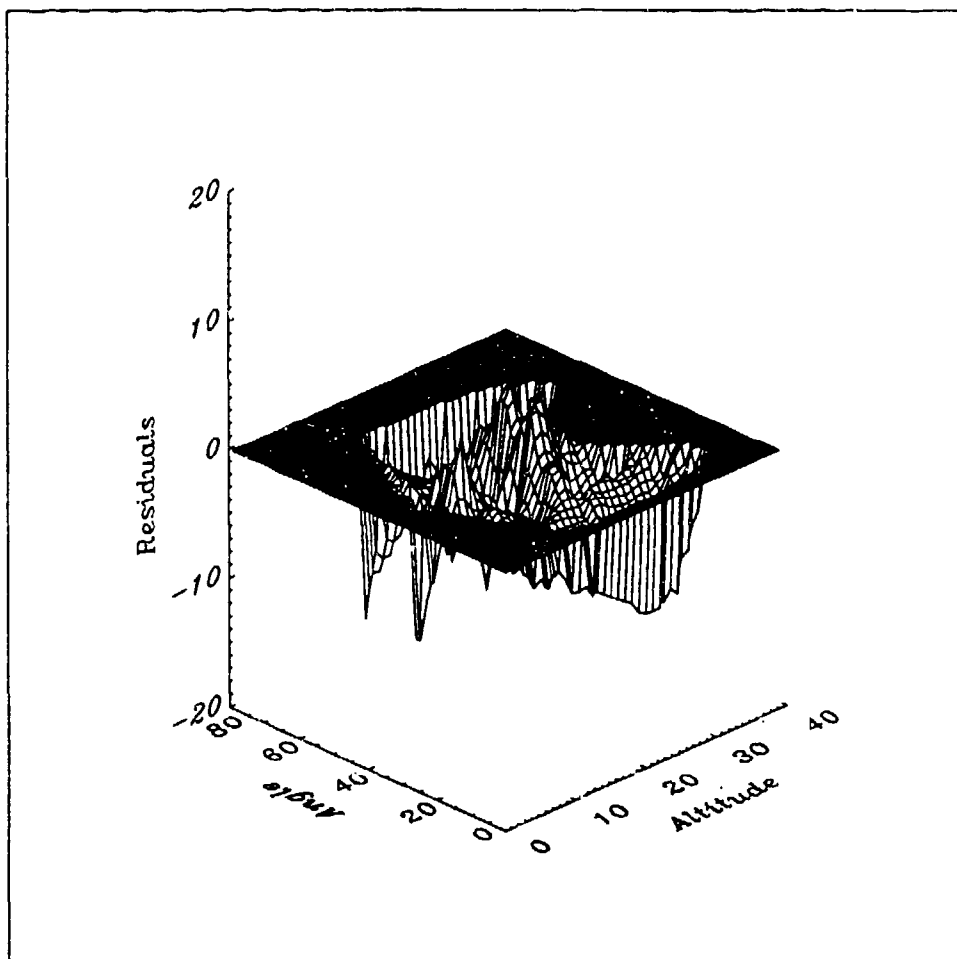
Subject 09 Kriged Residuals



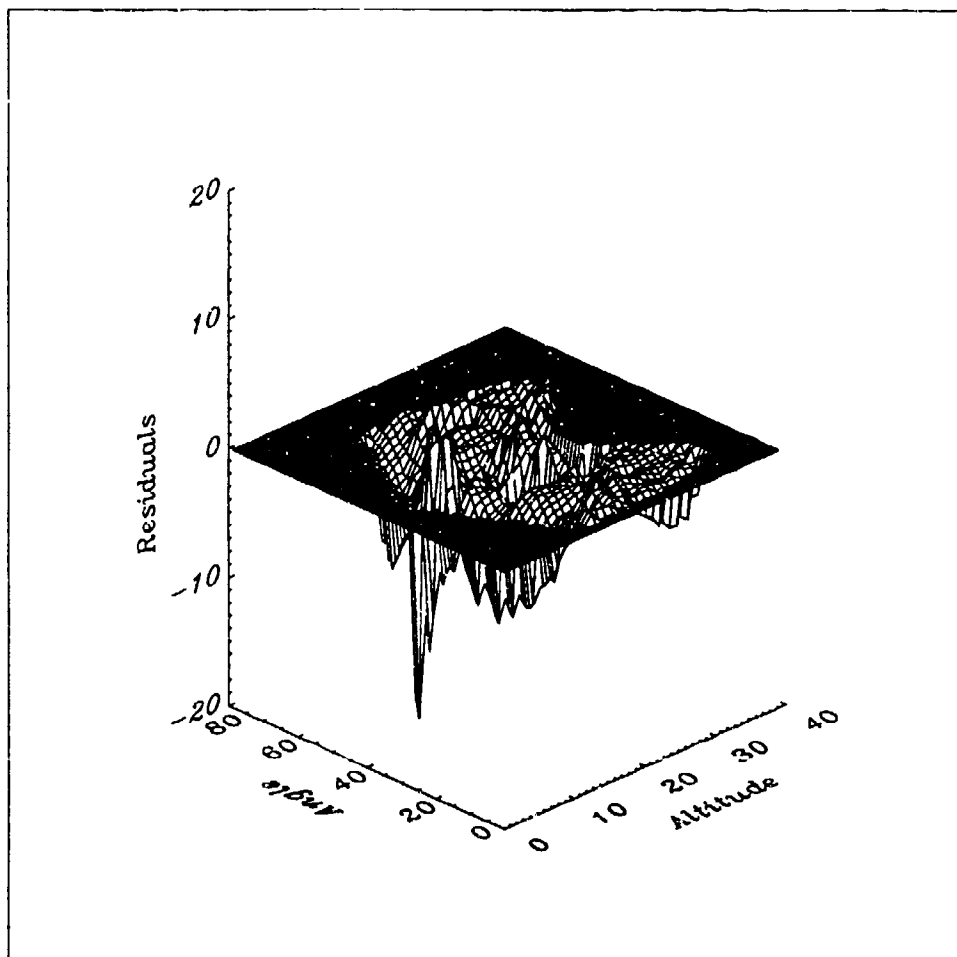
Subject 10 Kriged Residuals



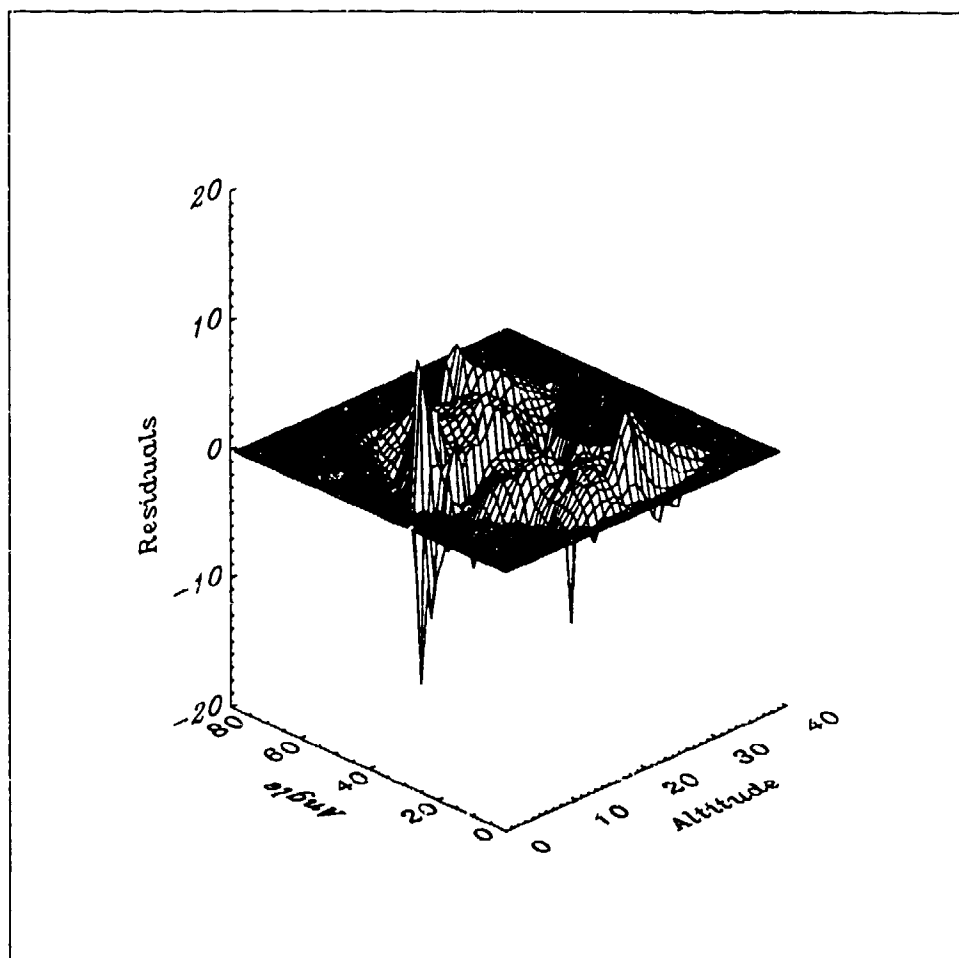
Subject 60 Kriged Residuals



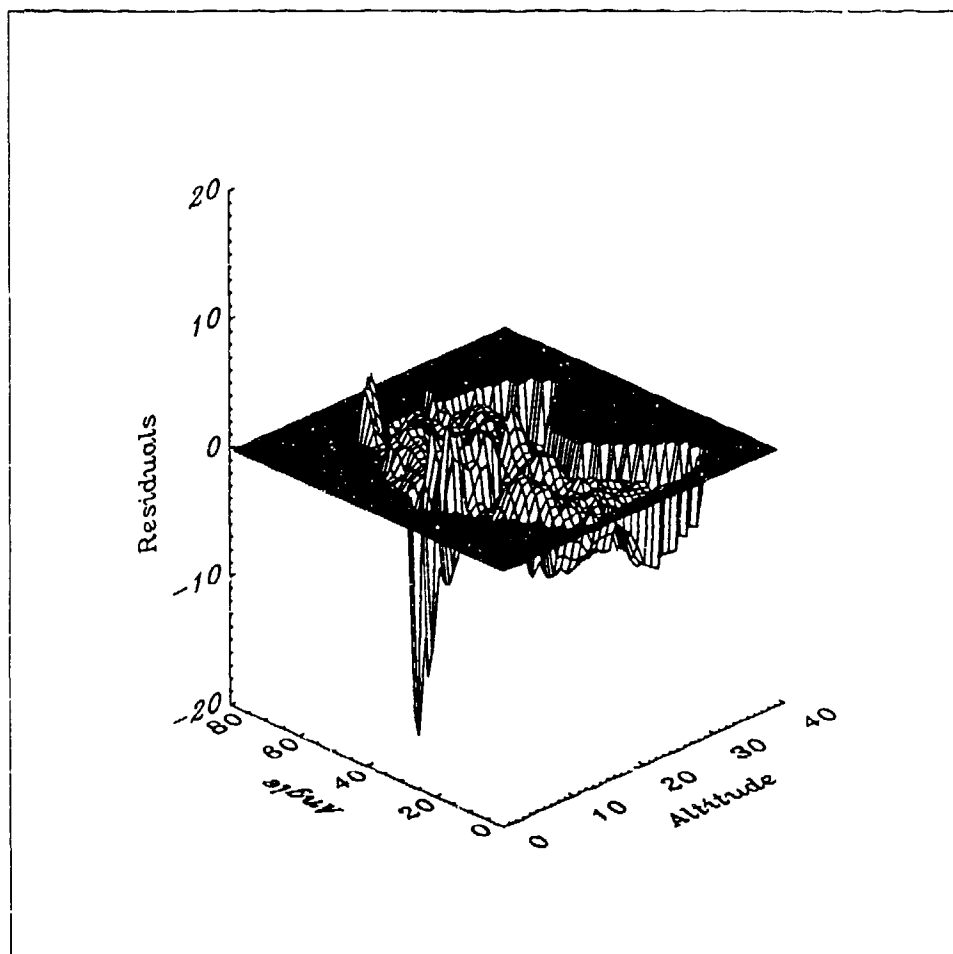
Subject 68 Kriged Residuals



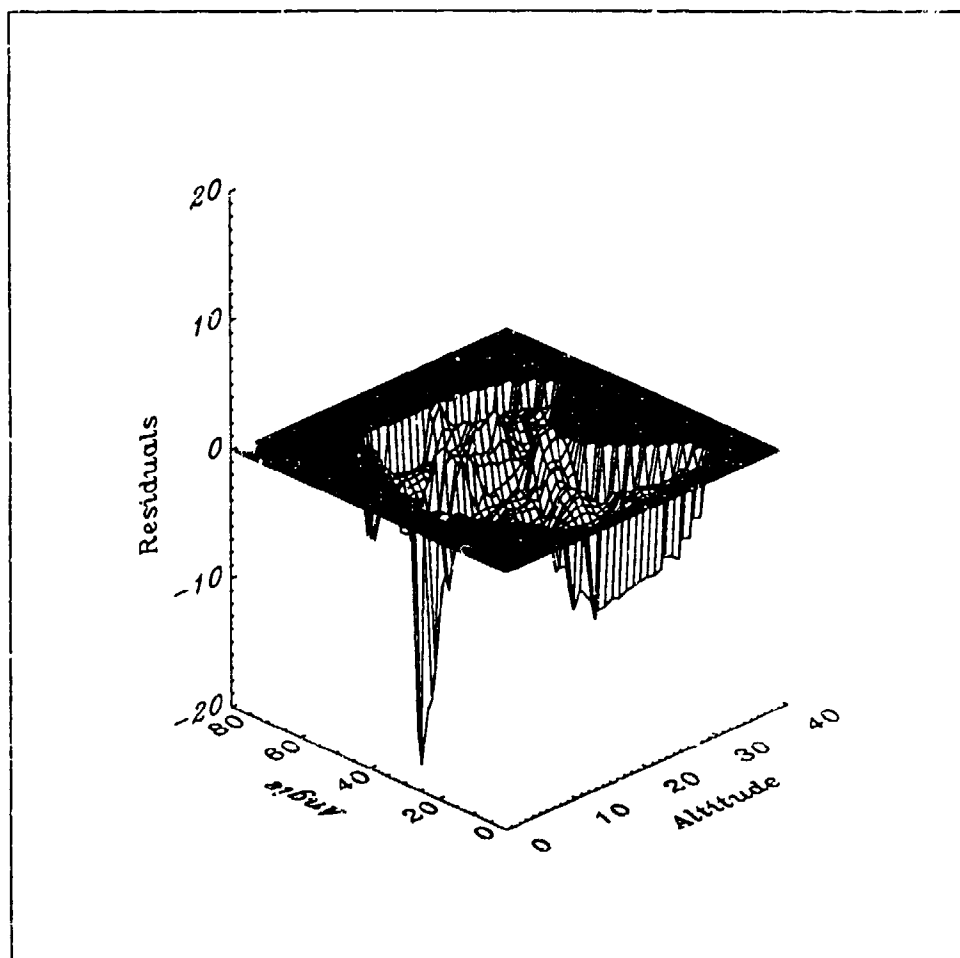
Subject 114 Kriged Residuals



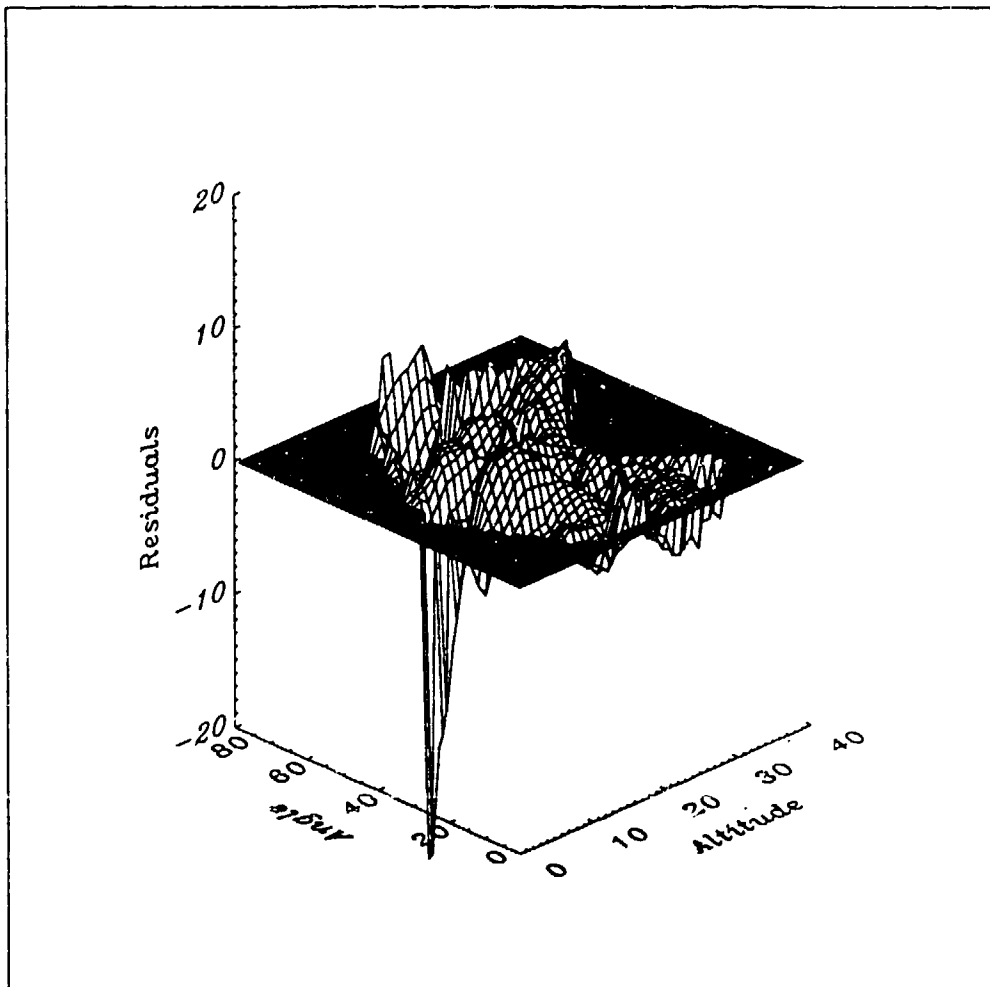
Subject 116 Kriged Residuals



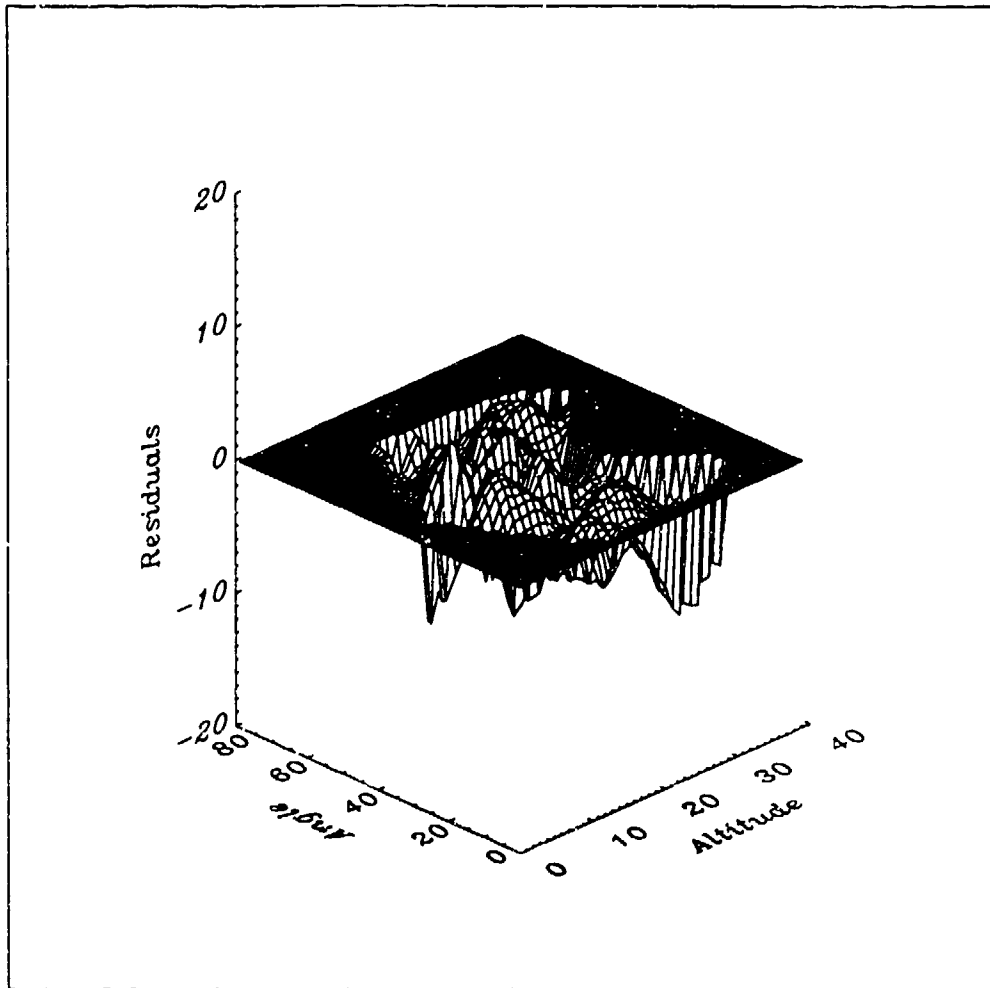
Subject 118 Kriged Residuals



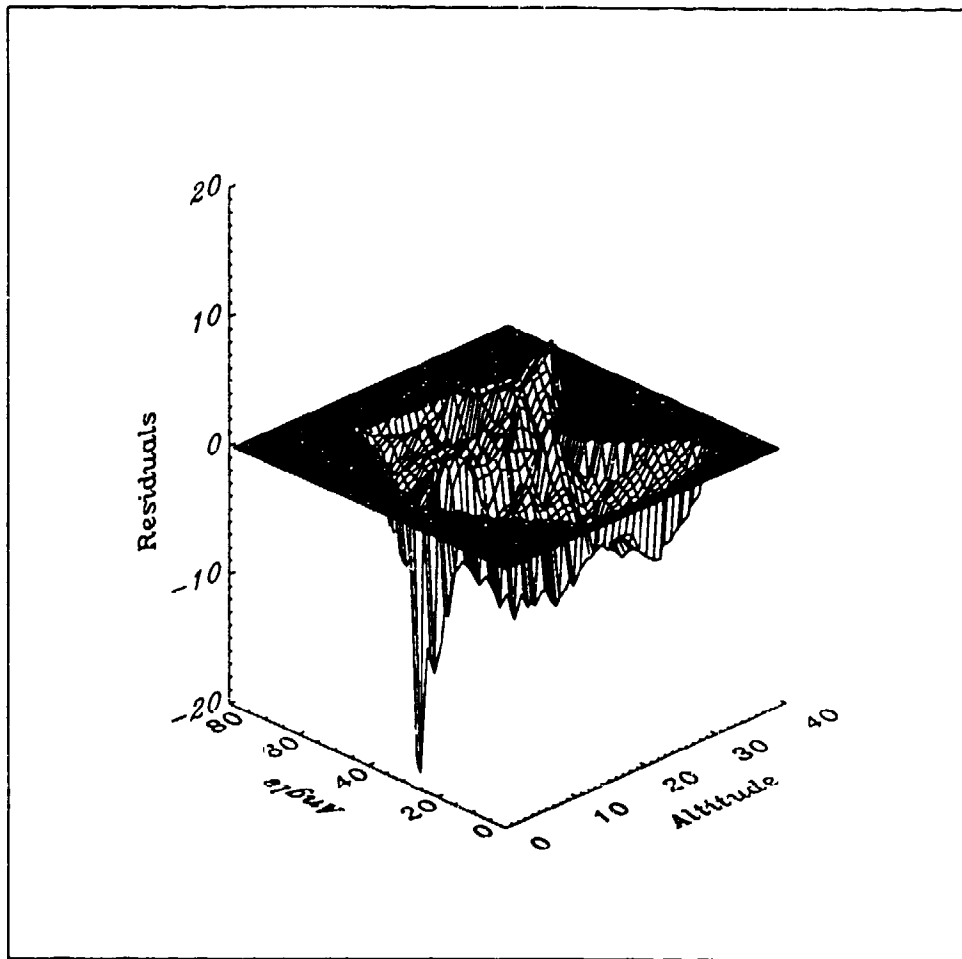
Subject 122 Kriged Residuals



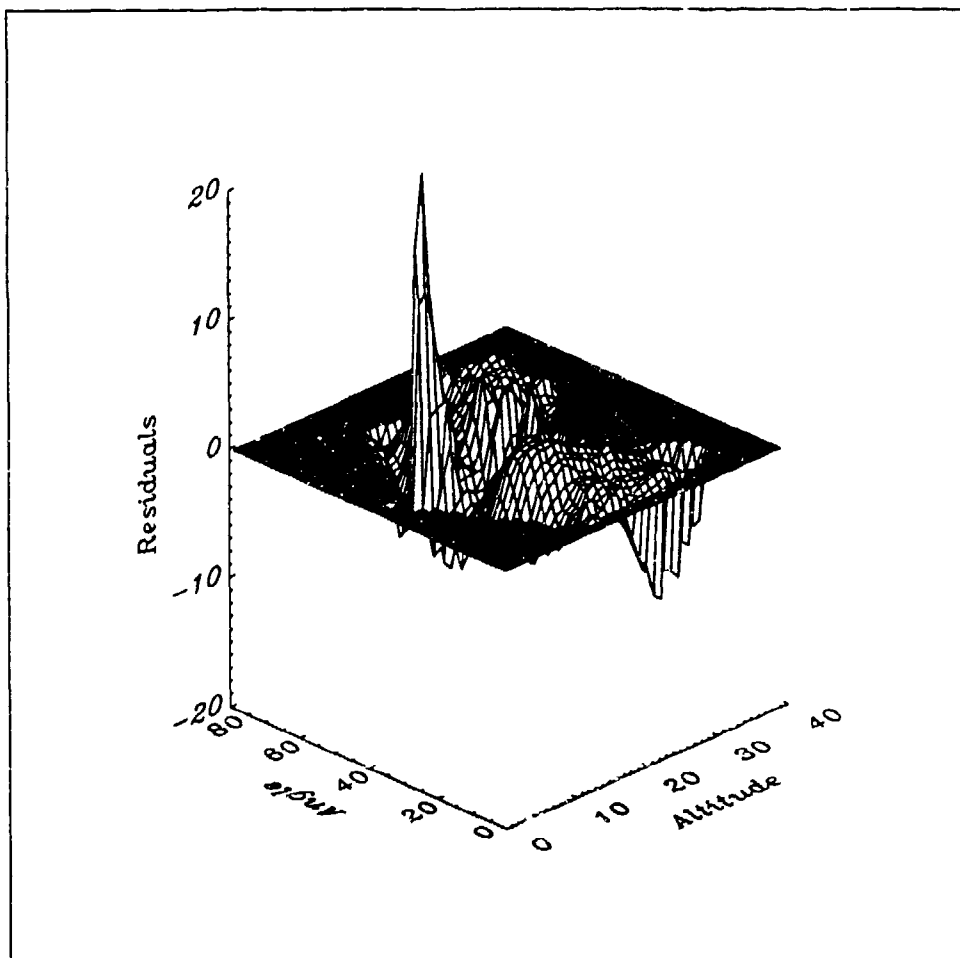
Subject 130 Kriged Residuals



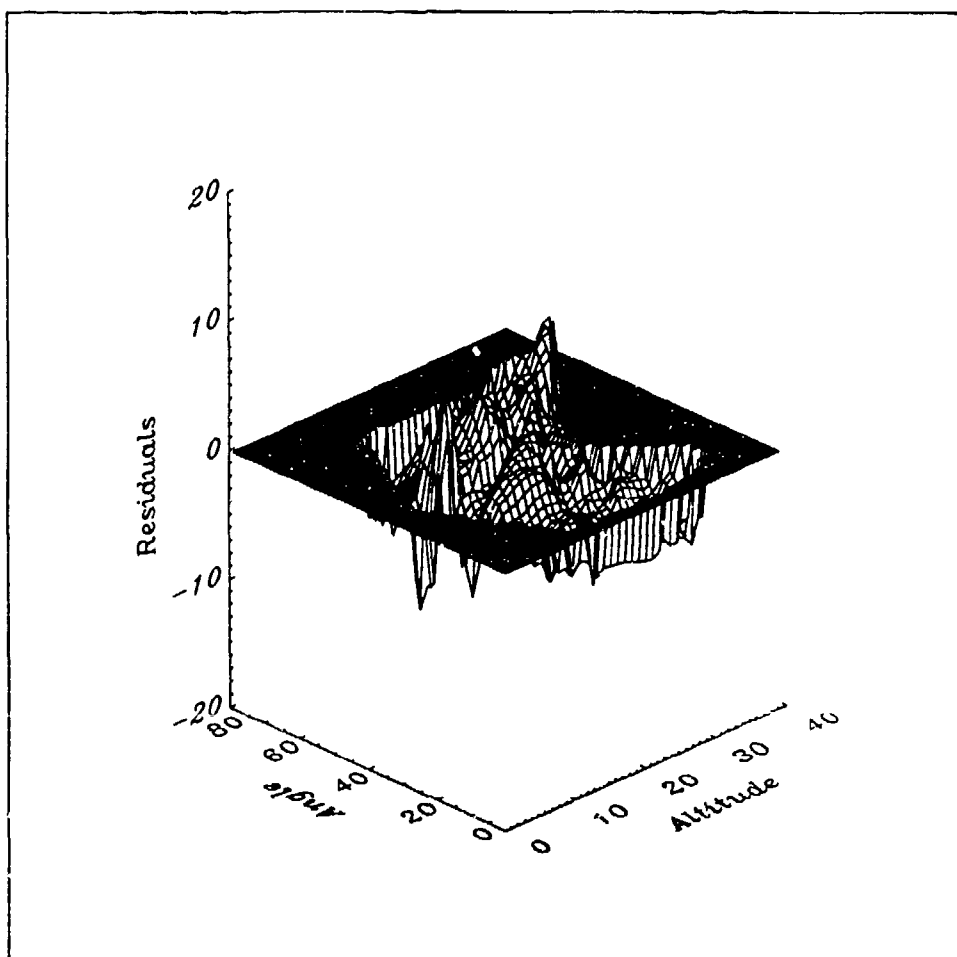
Subject 133 Kriged Residuals



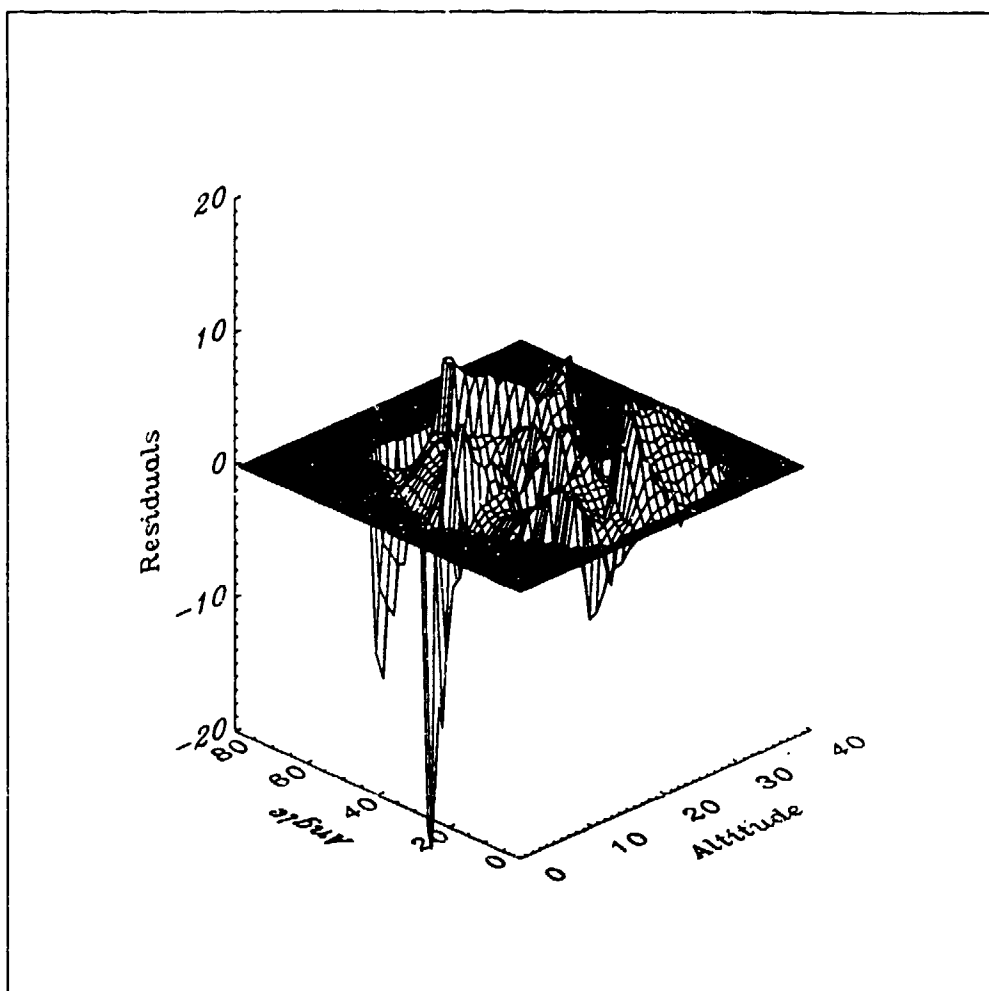
Subject 136 Kriged Residuals



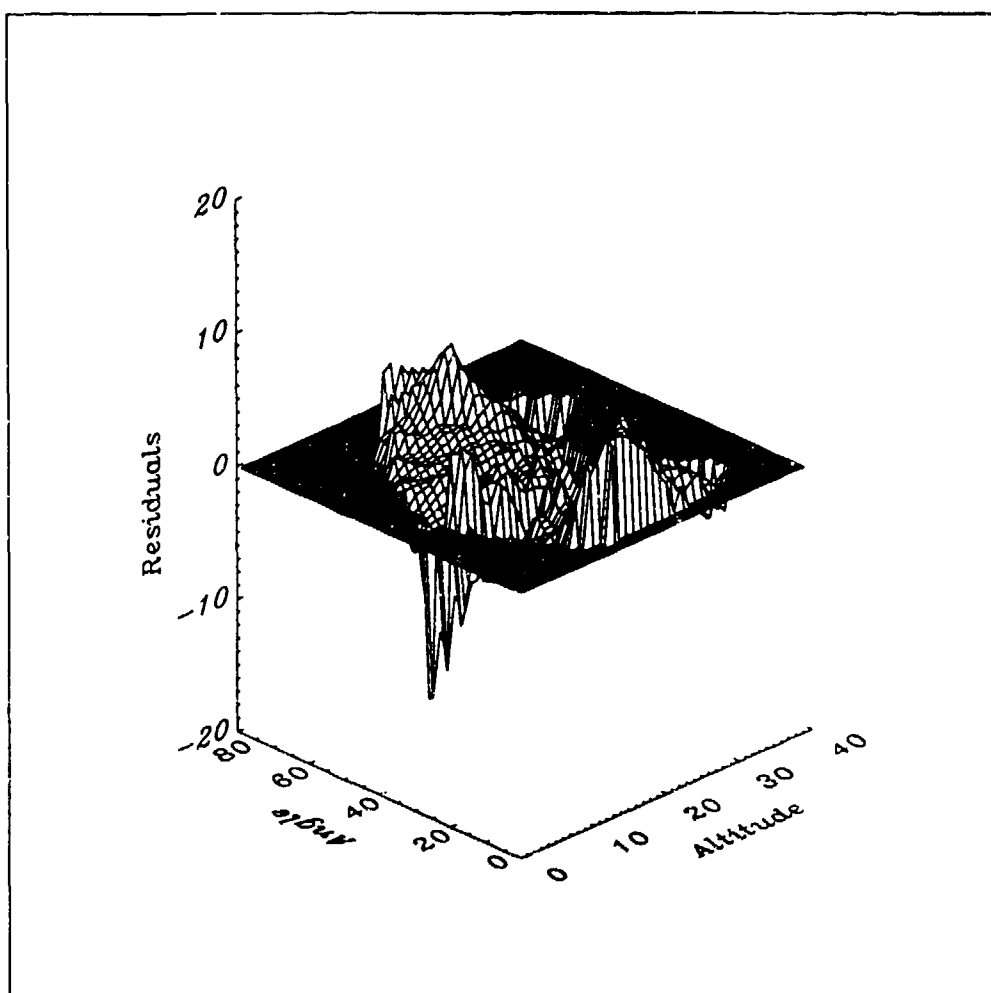
Subject 140 Kriged Residuals



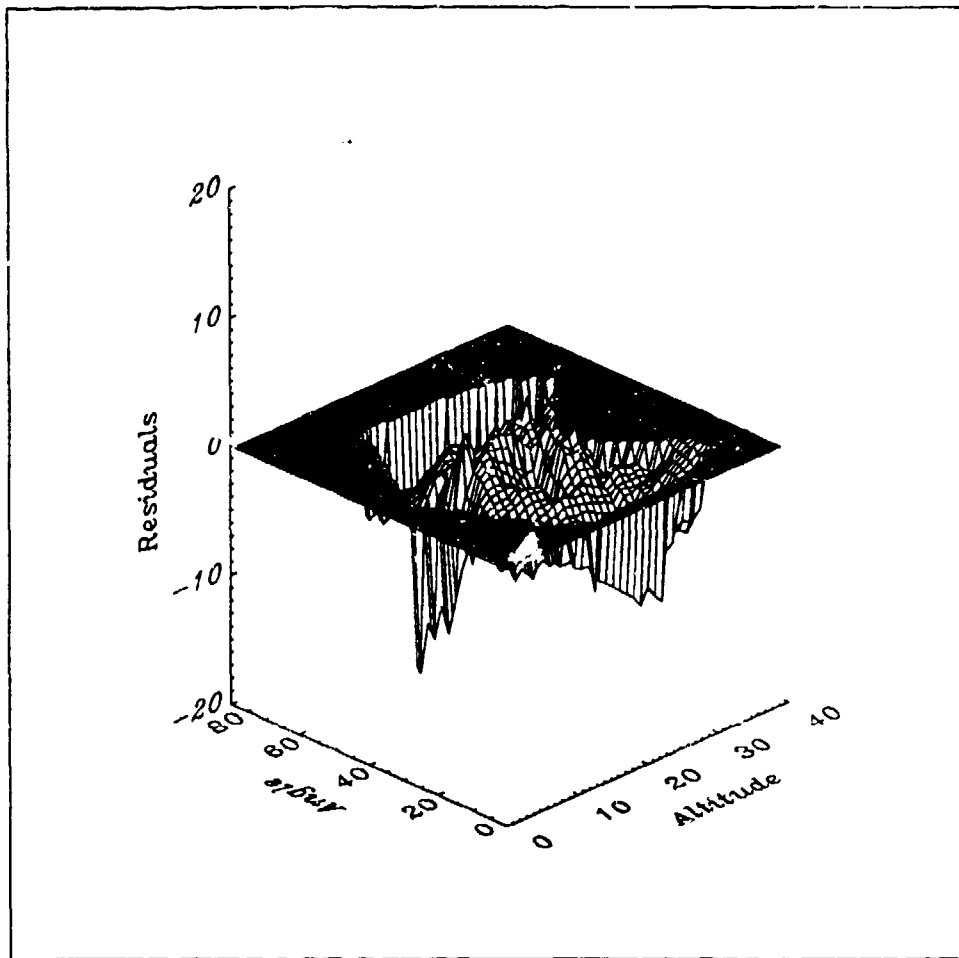
Subject 142 Kriged Residuals



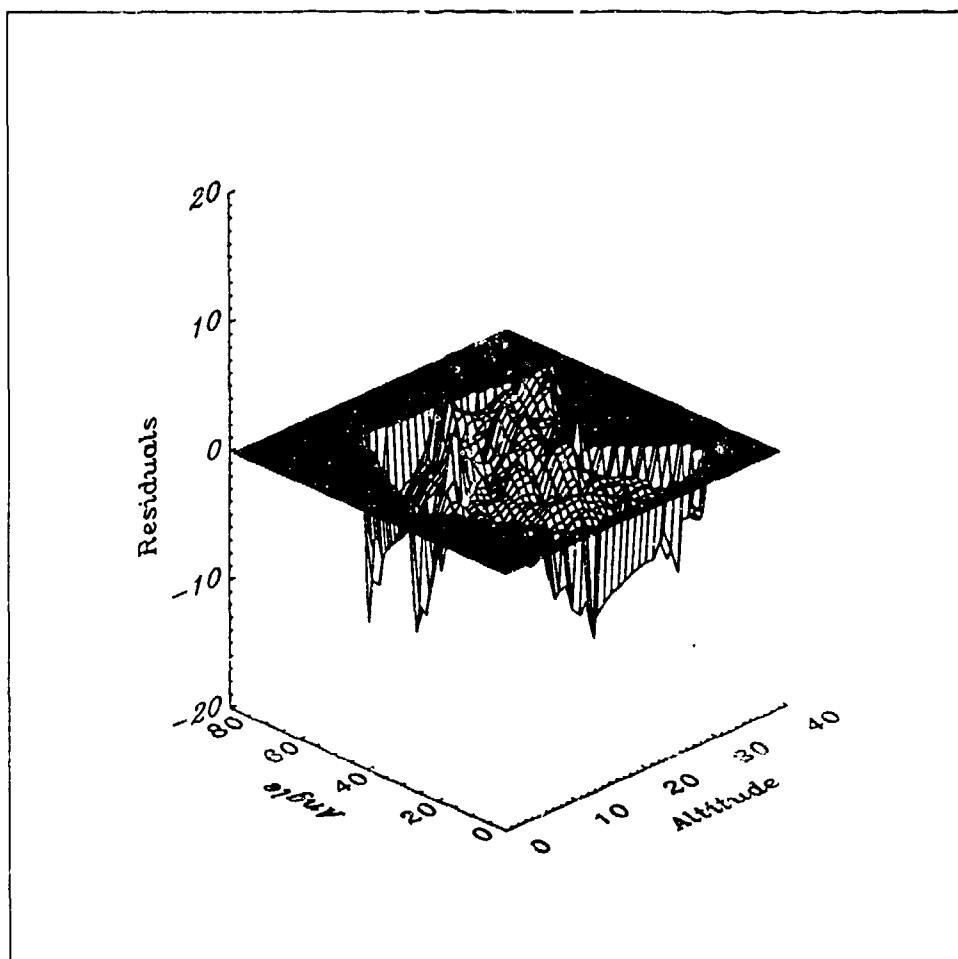
Subject 153 Kriged Residuals



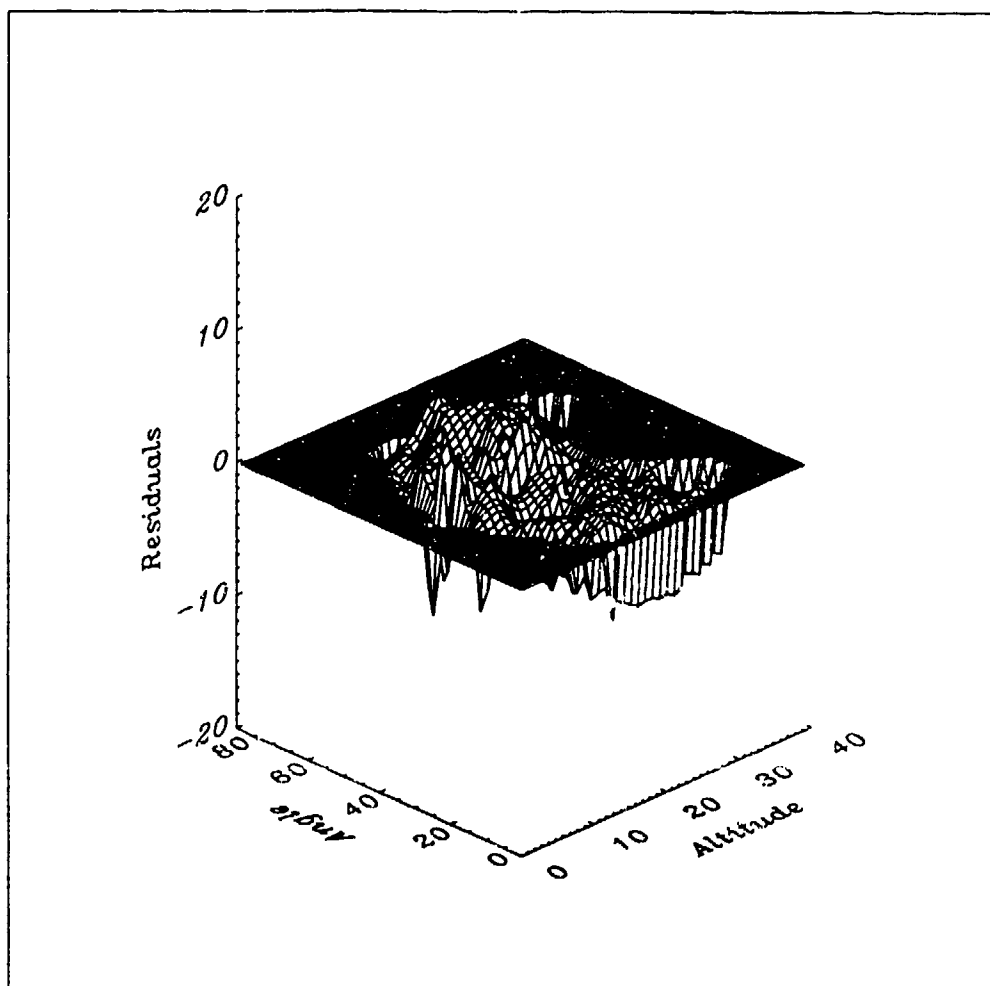
Subject 154 Kriged Residuals



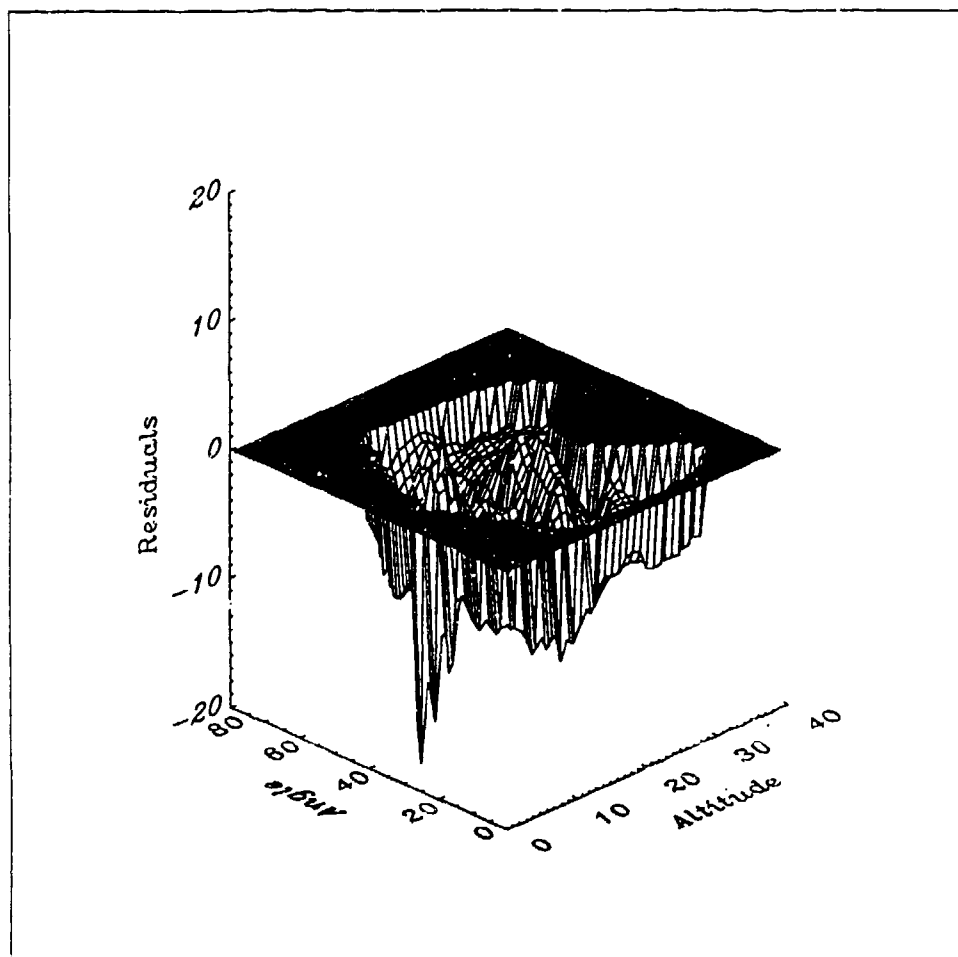
Subject 155 Kriged Residuals



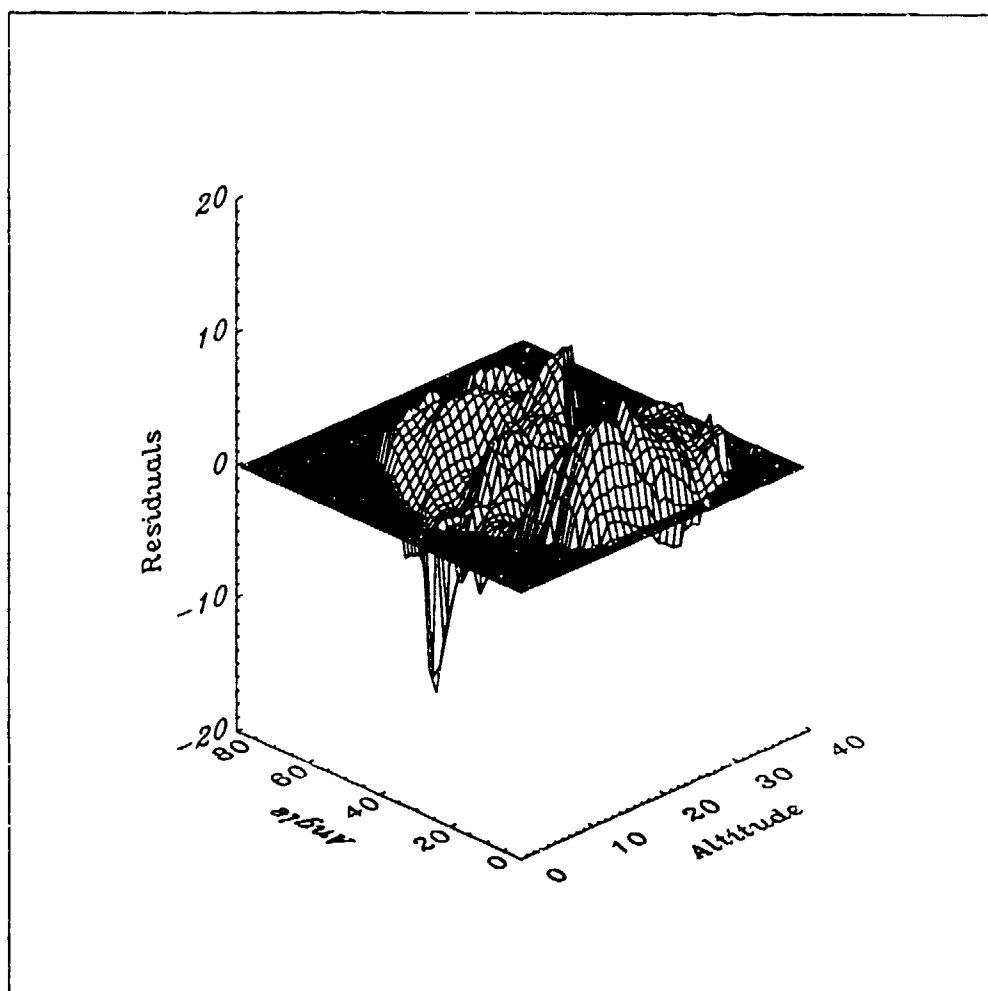
Subject 159 Kriged Residuals



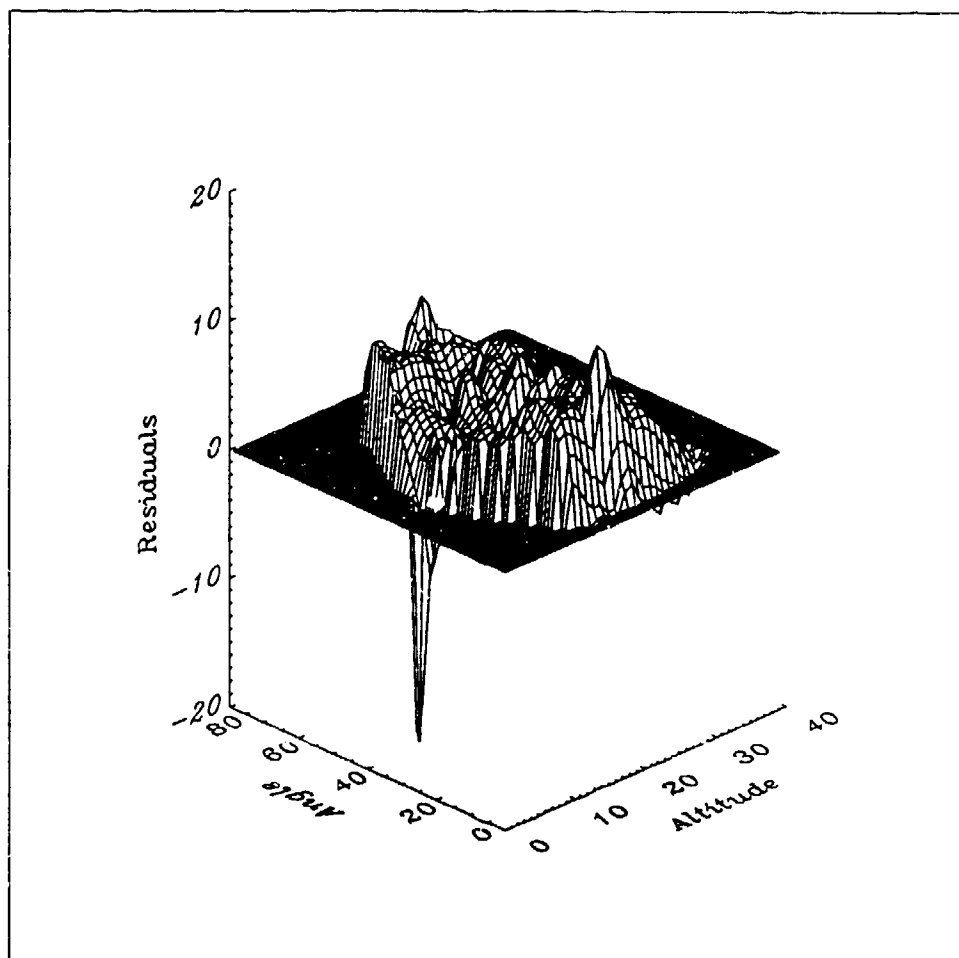
Subject 160 Kriged Residuals



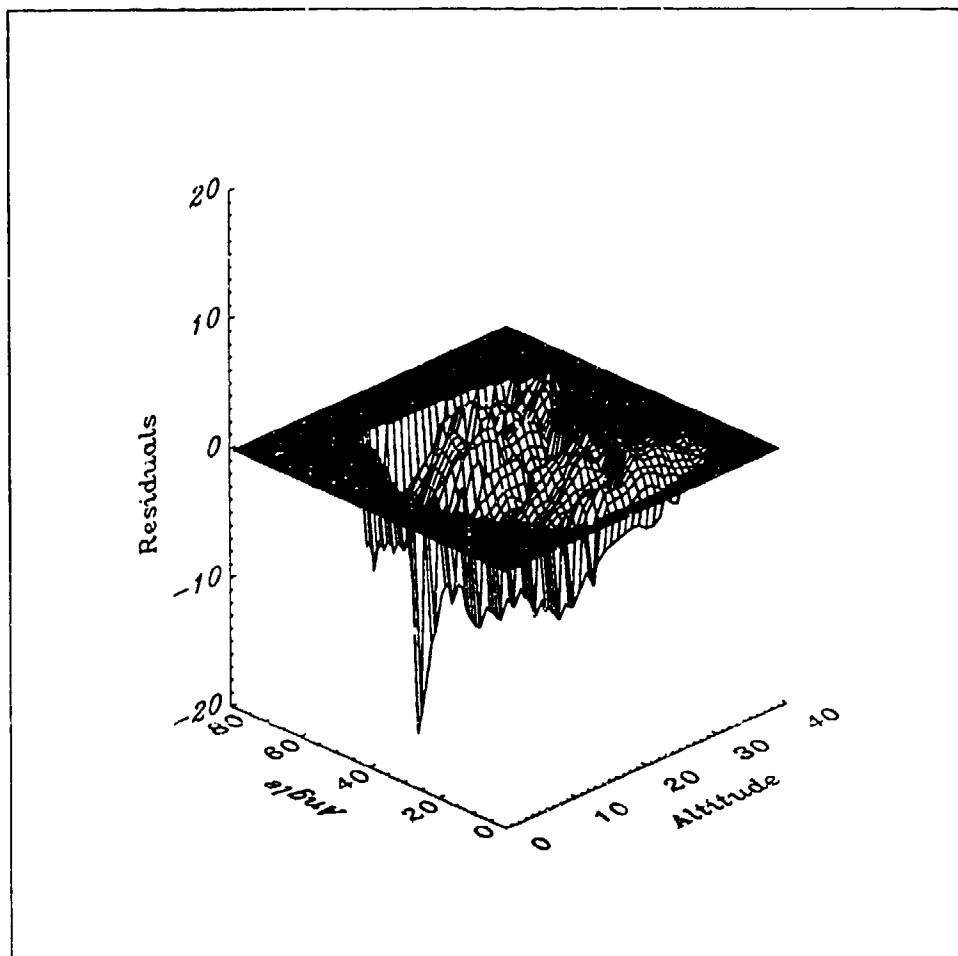
Subject 161 Kriged Residuals



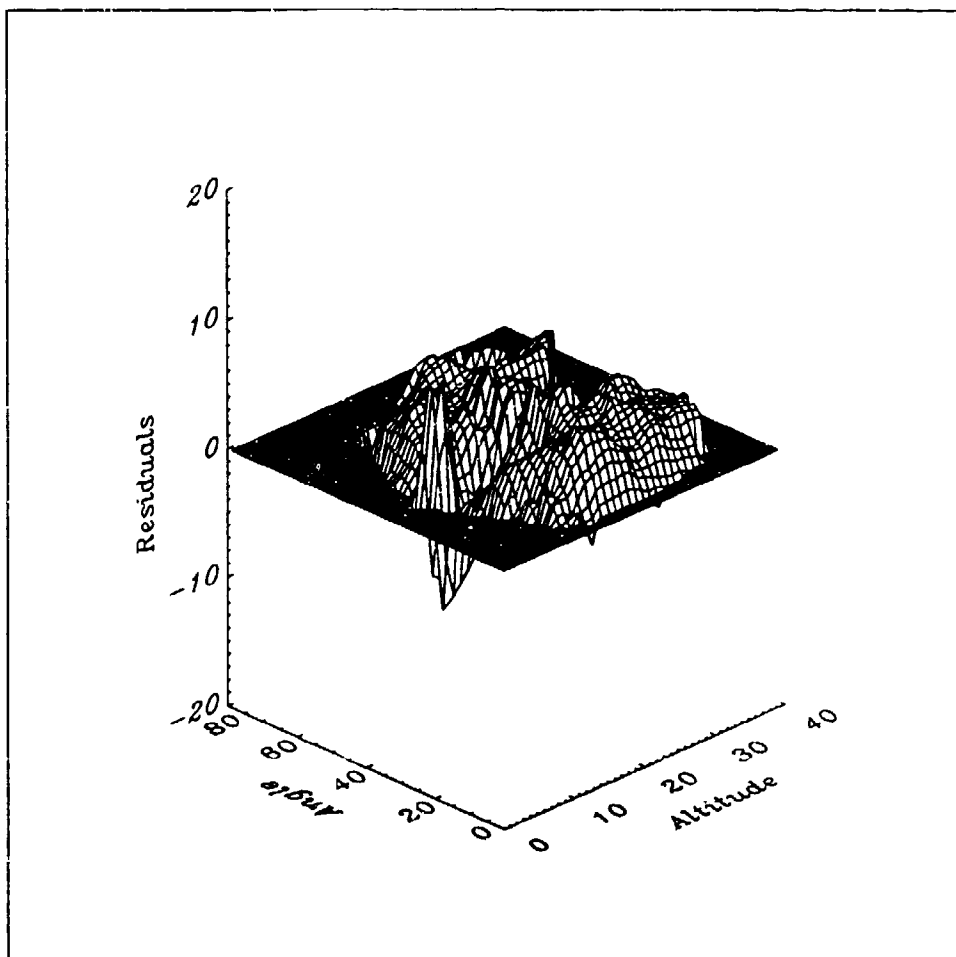
Subject 167 Kriged Residuals



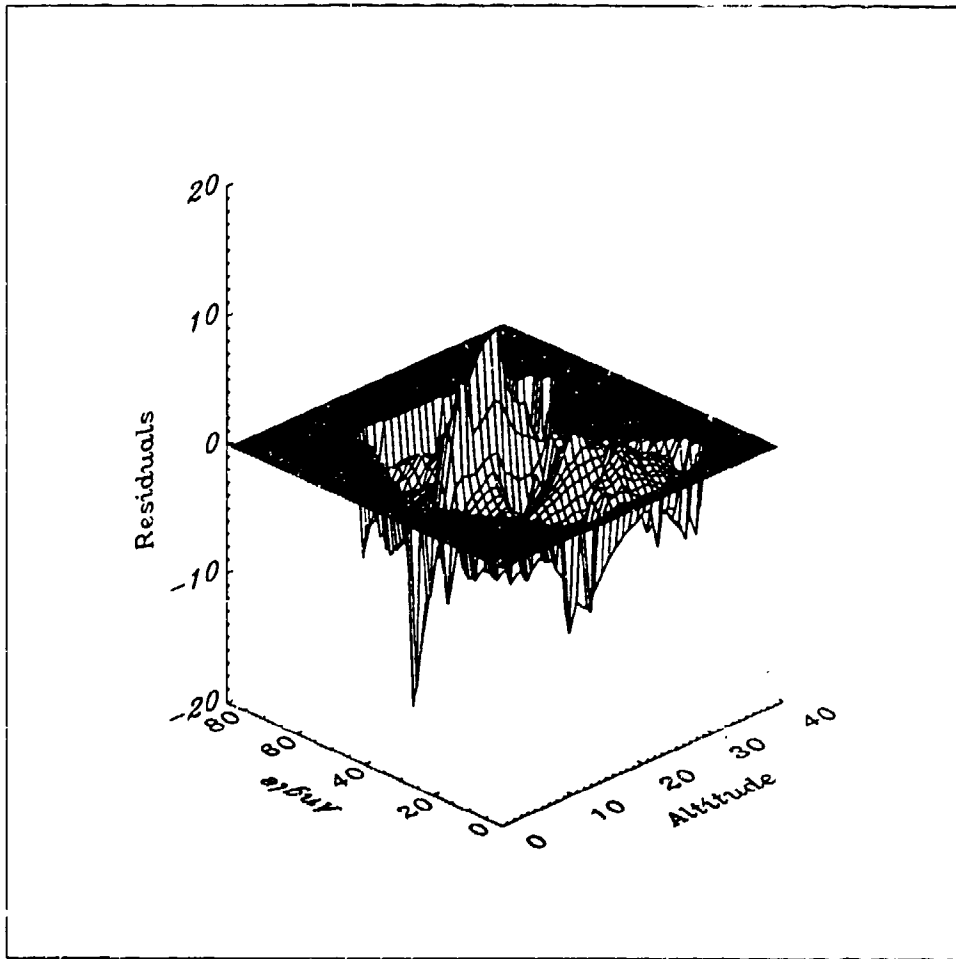
Subject 171 Kriged Residuals



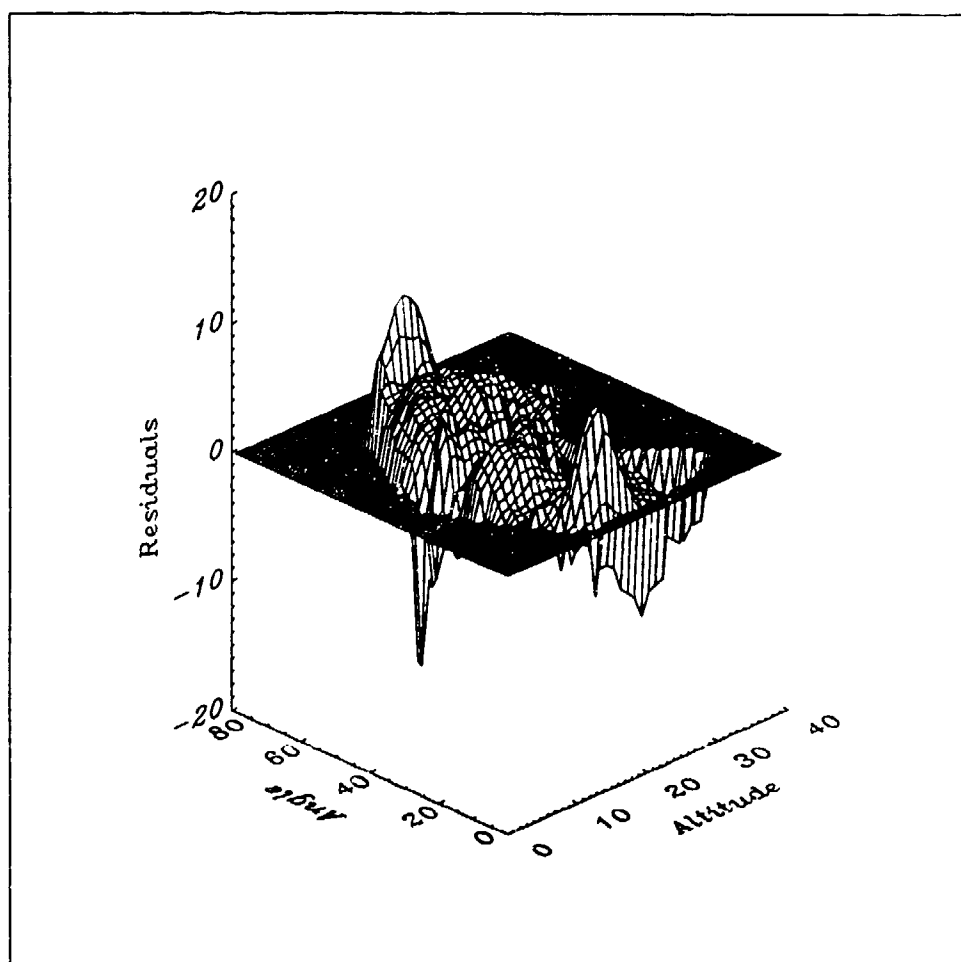
Subject 173 Kriged Residuals



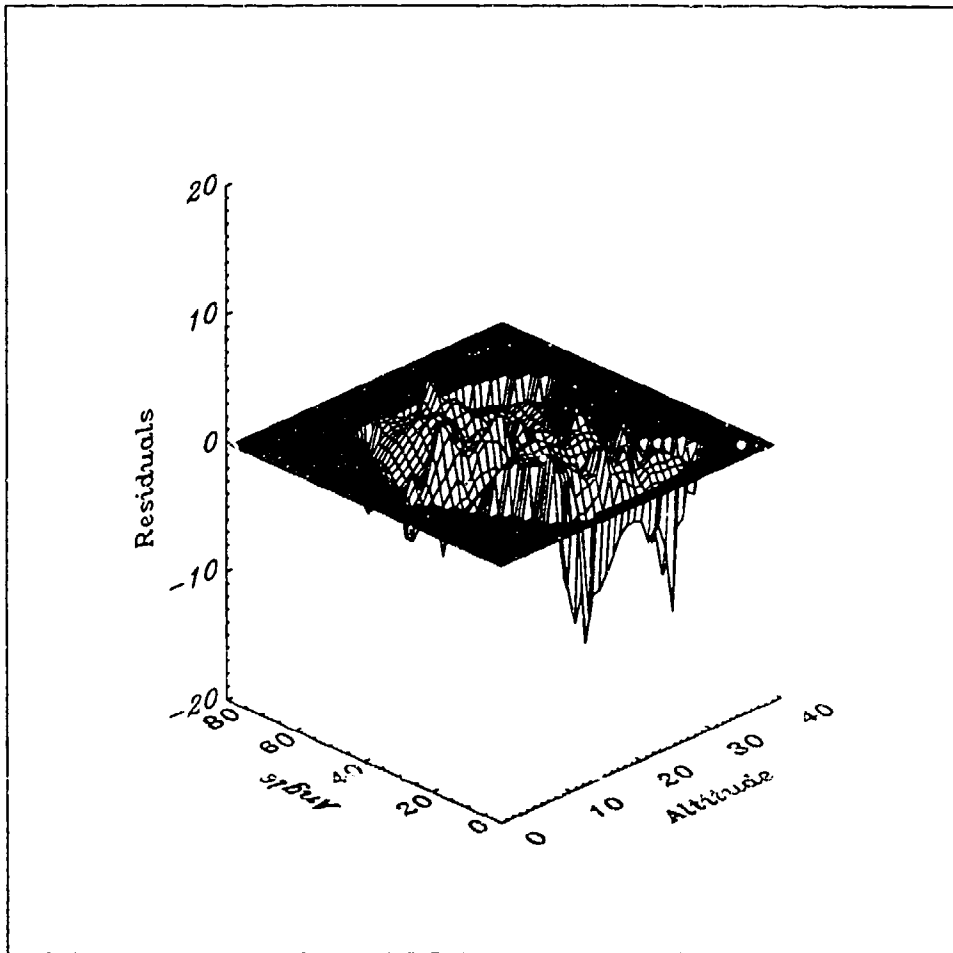
Subject 176 Kriged Residuals



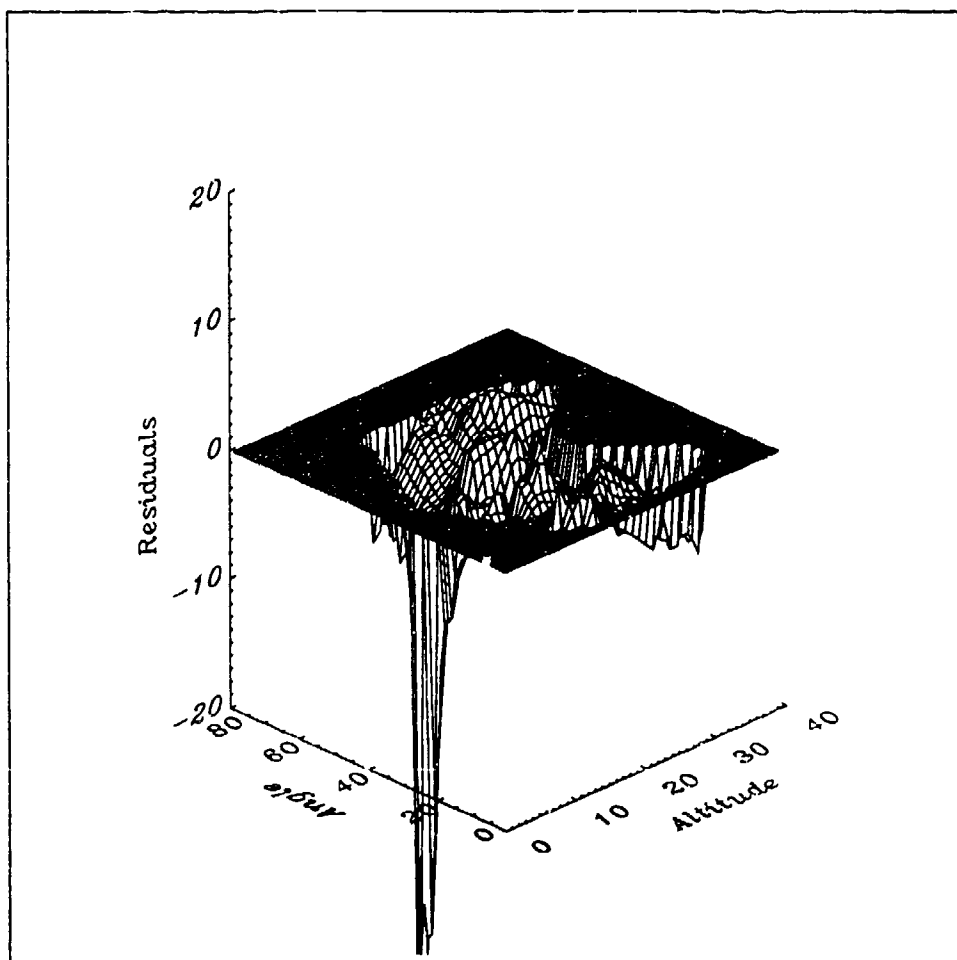
Subject 183 Kriged Residuals



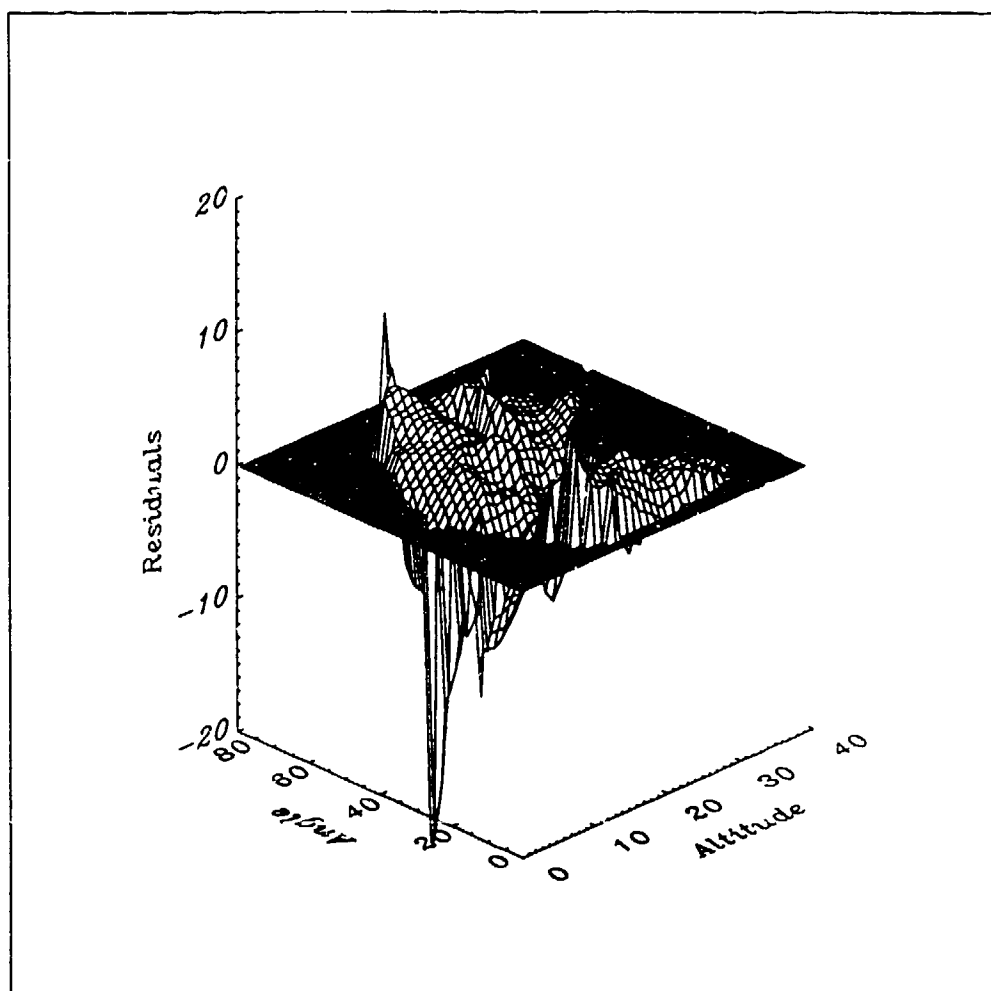
Subject 185 Kriged Residuals



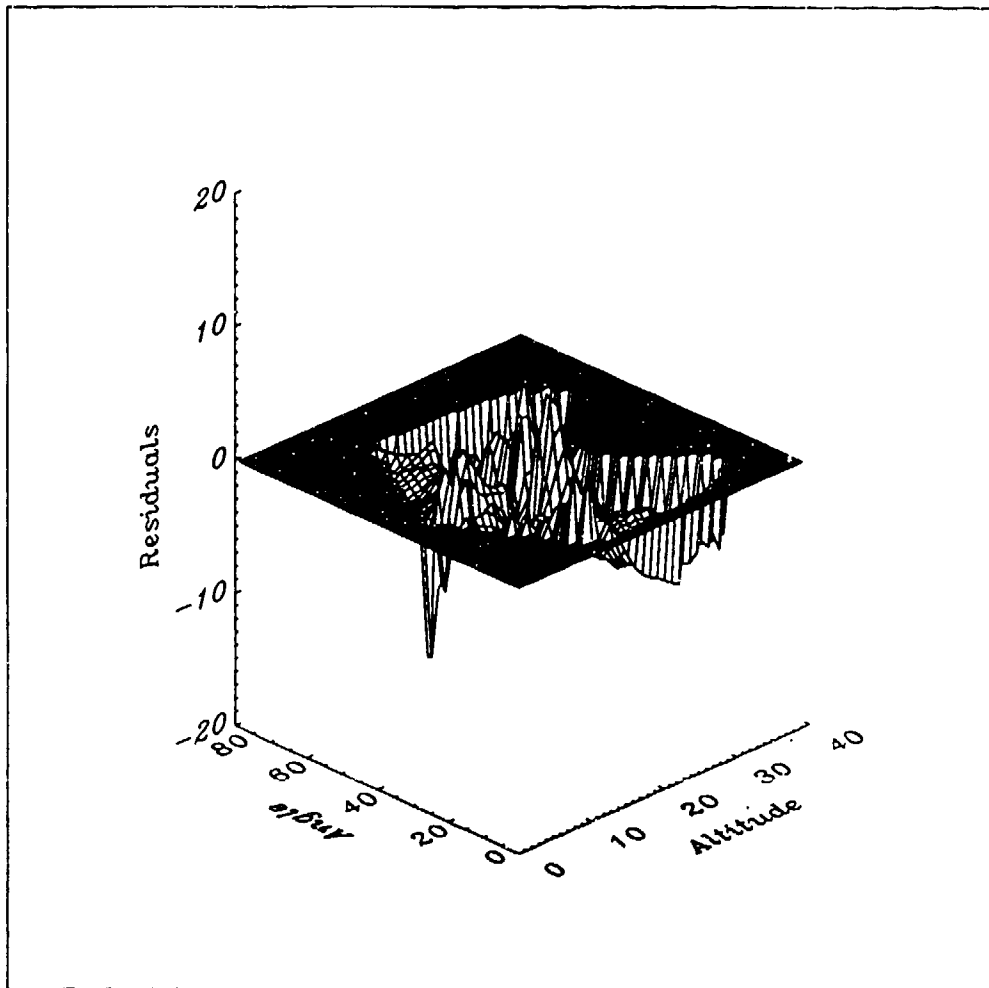
Subject 112 Kriged Residuals



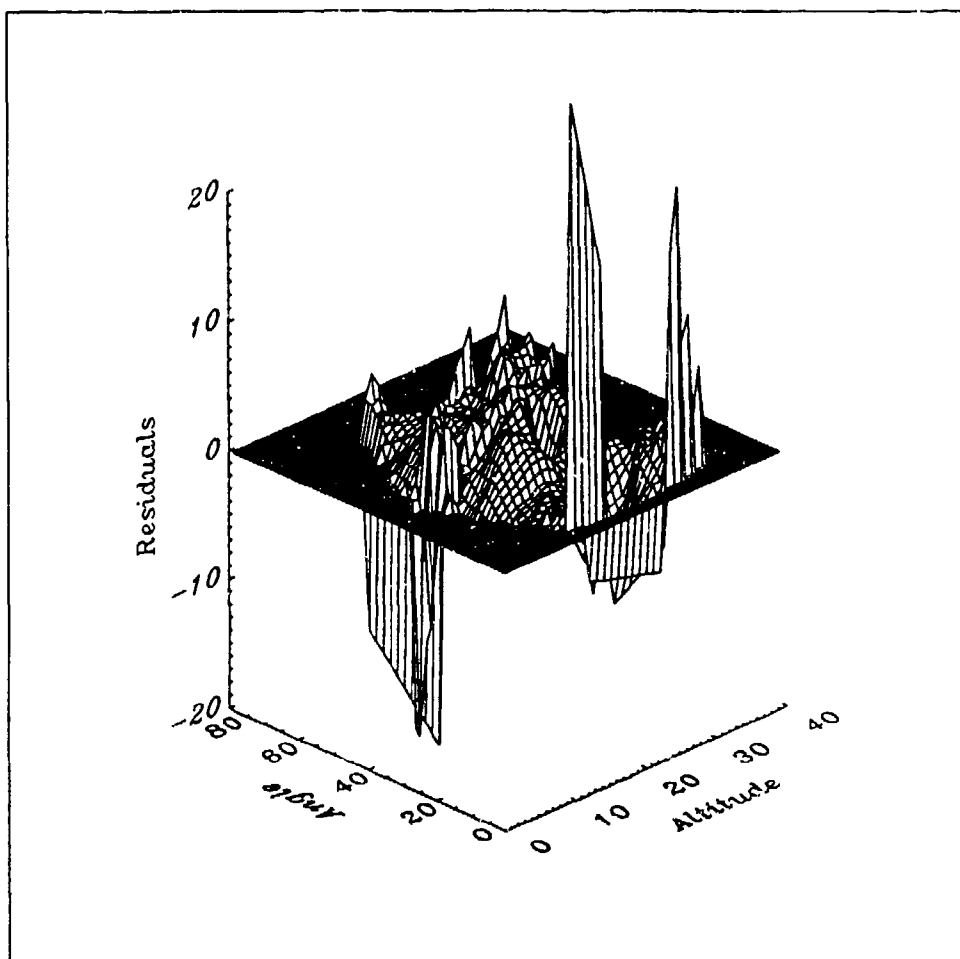
Subject 141 Kriged Residuals



Subject 152 Kriged Residuals



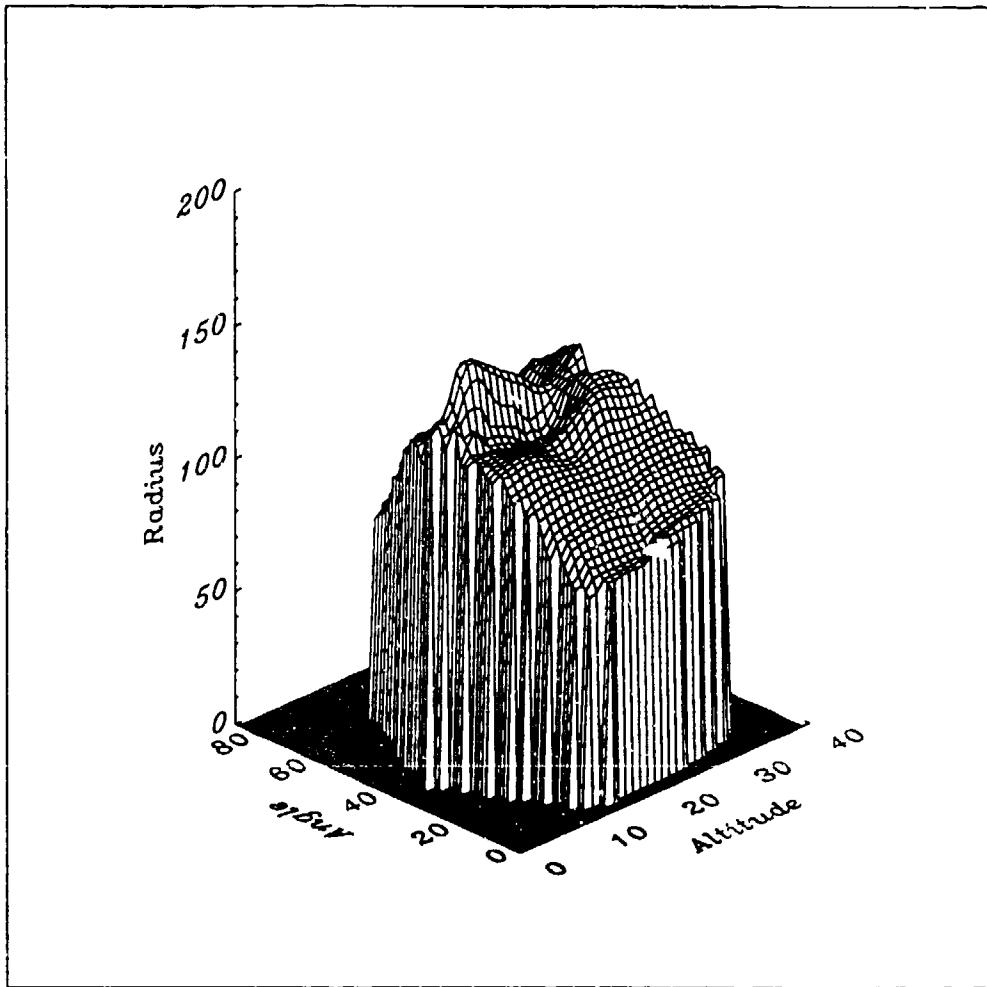
Subject 156 Kriged Residuals



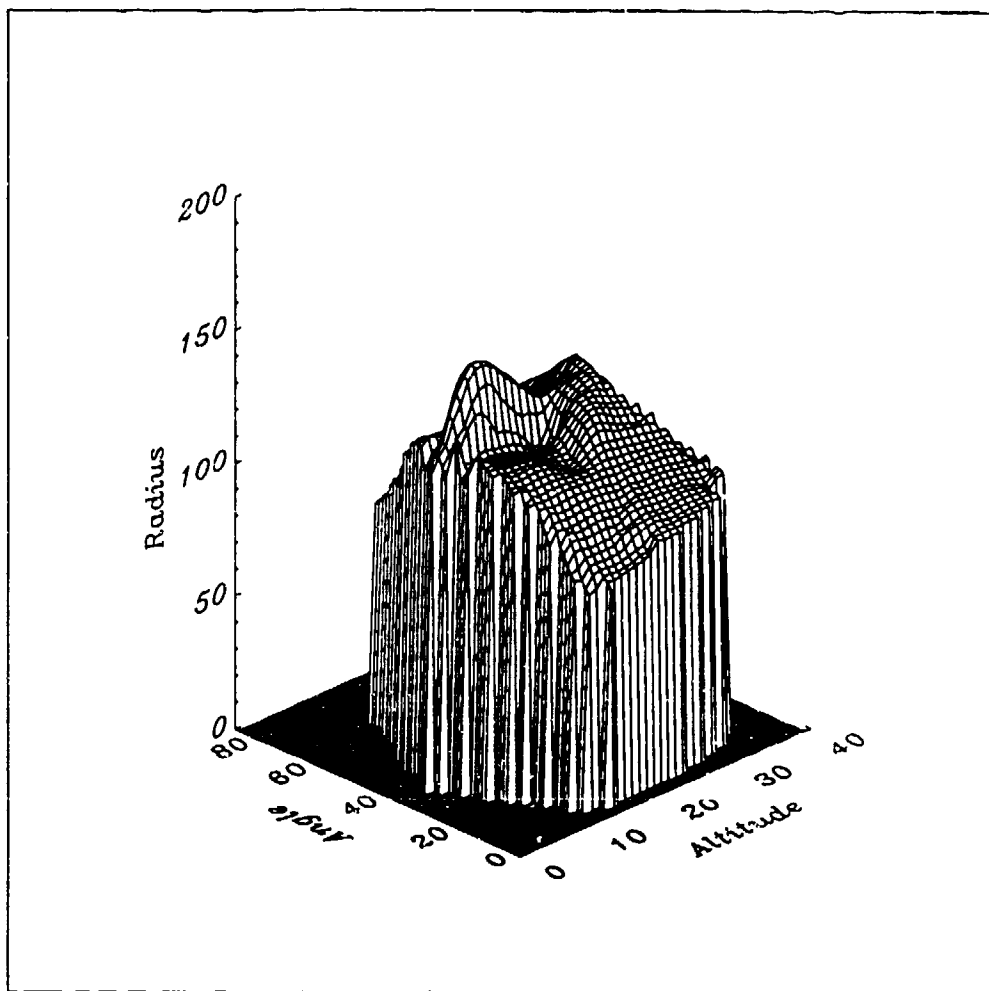
Subject 199 Kriged Residuals

### *Kriged Facial Surfaces*

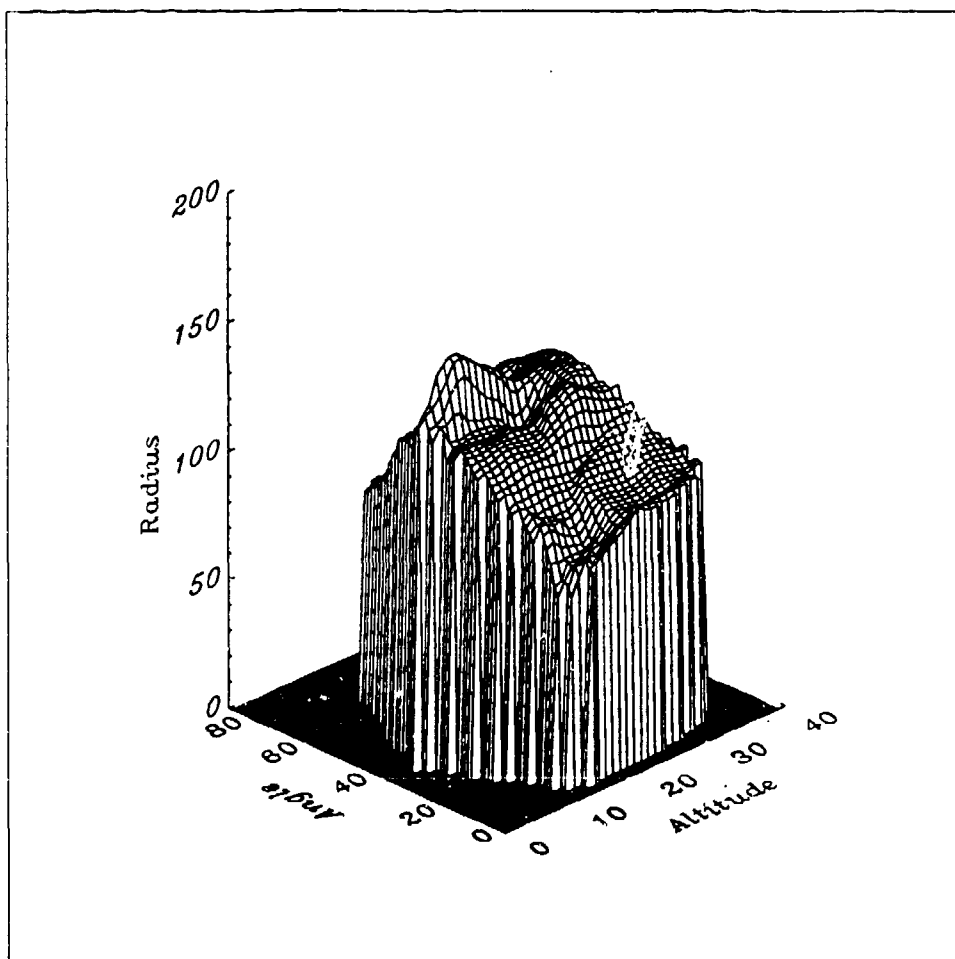
This section provides the kriged facial surfaces for the 30 data sets. The kriged facial surfaces were obtained by combining the kriged residuals with the trend.



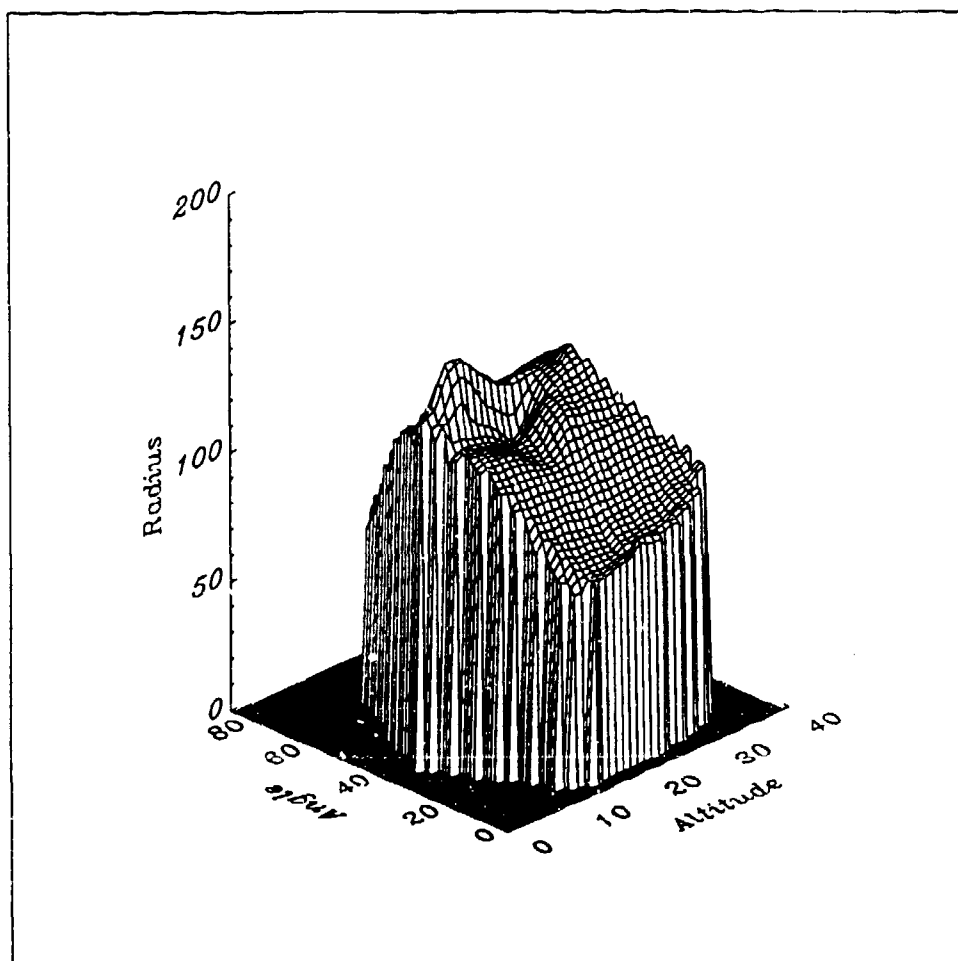
Subject 09 Kriged Surface



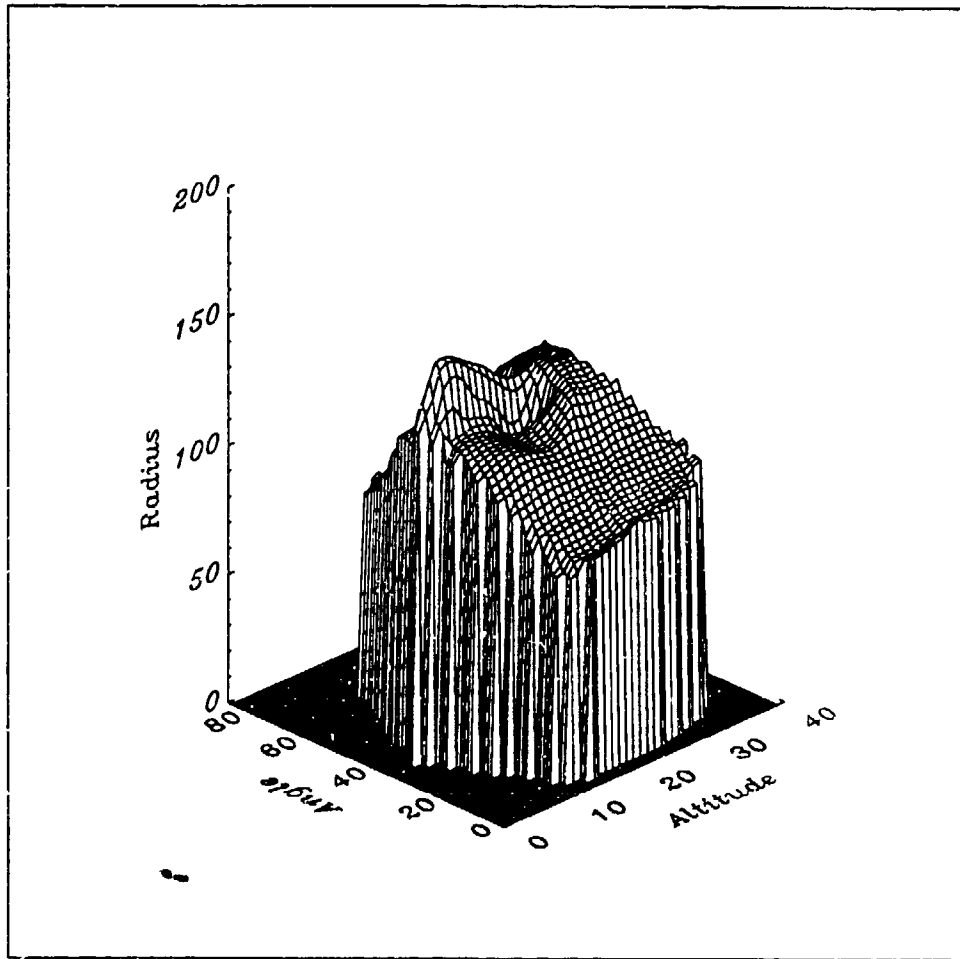
Subject 10 Kriged Surface



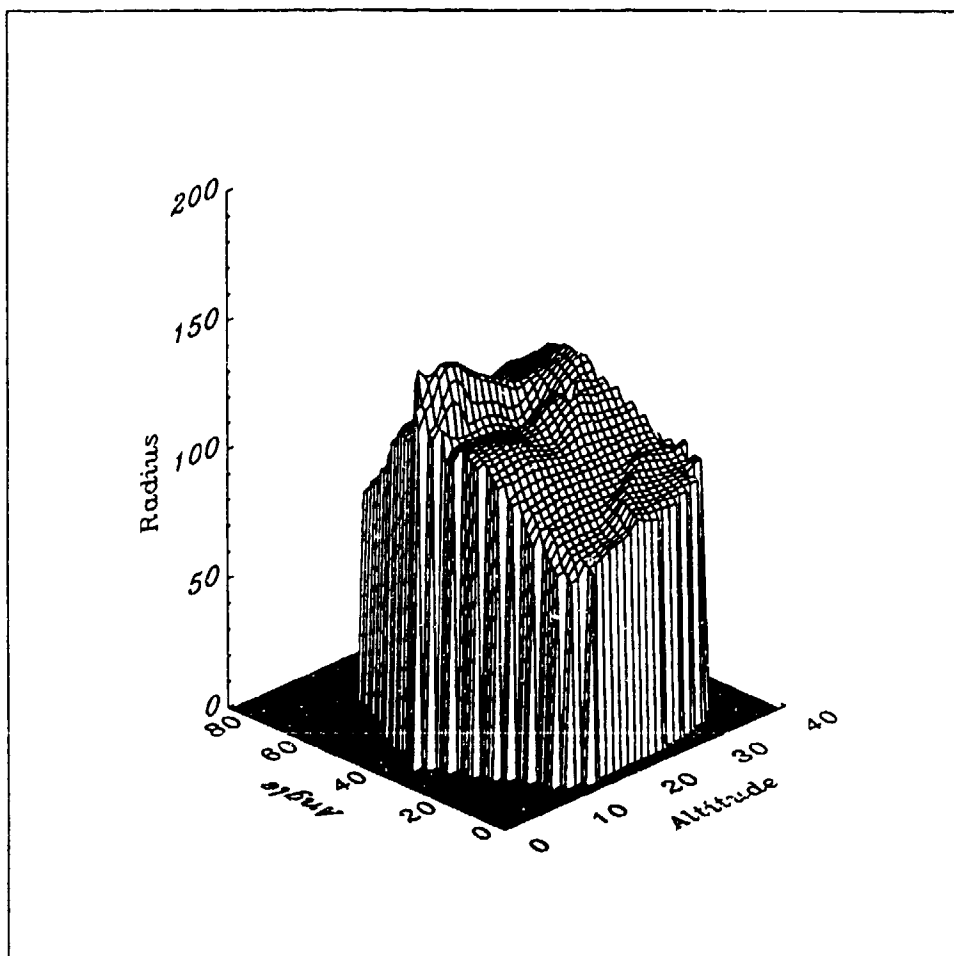
Subject 60 Kriged Surface



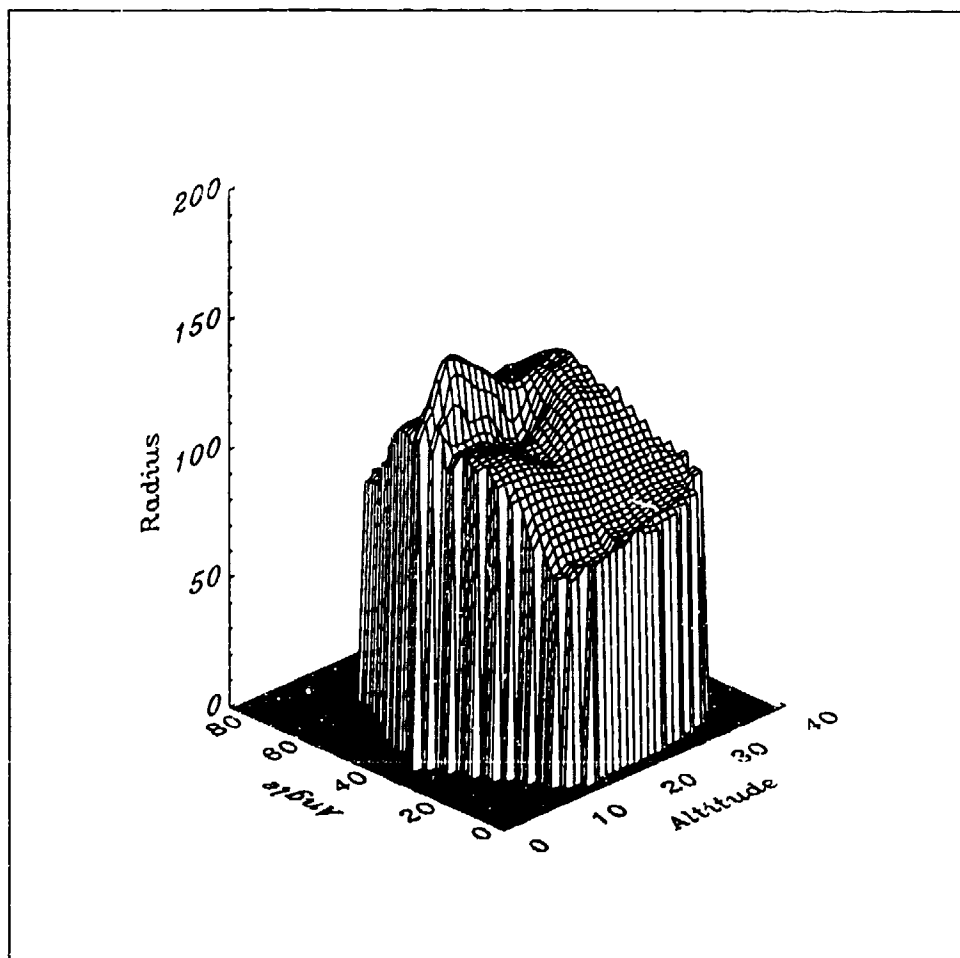
Subject 68 Kriged Surface



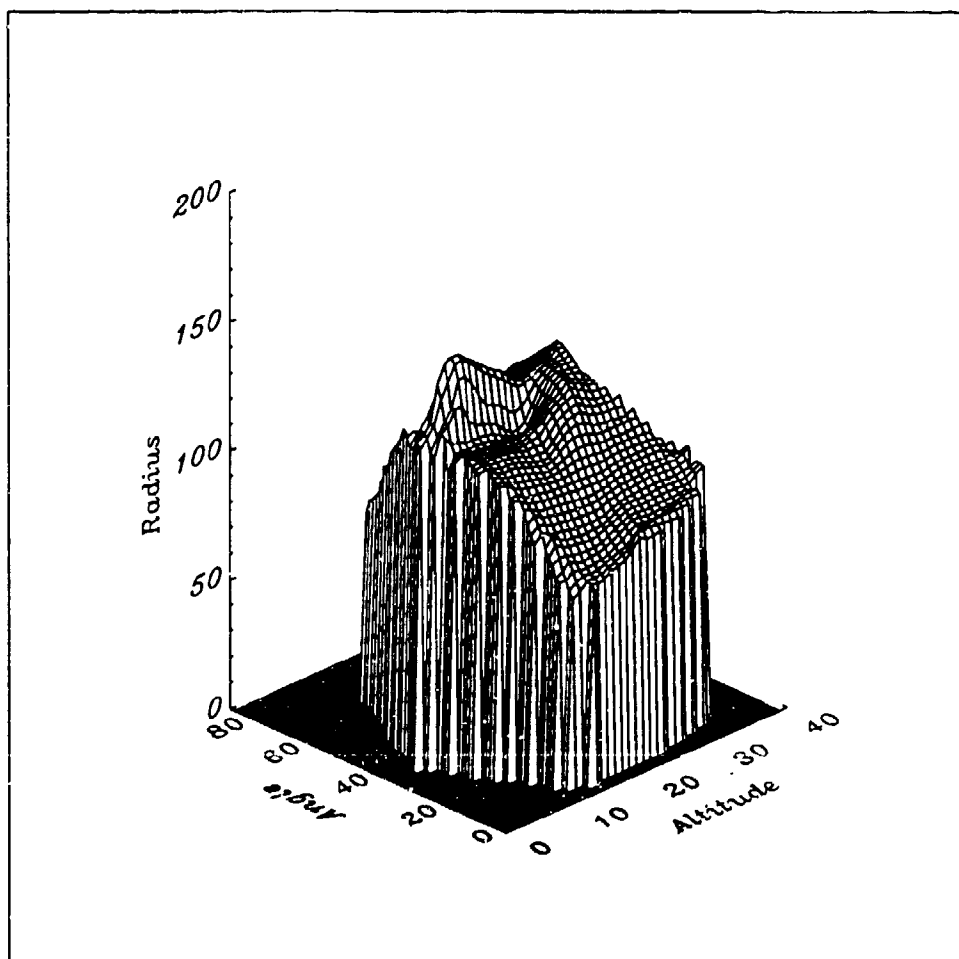
Subject 114 Kriged Surface



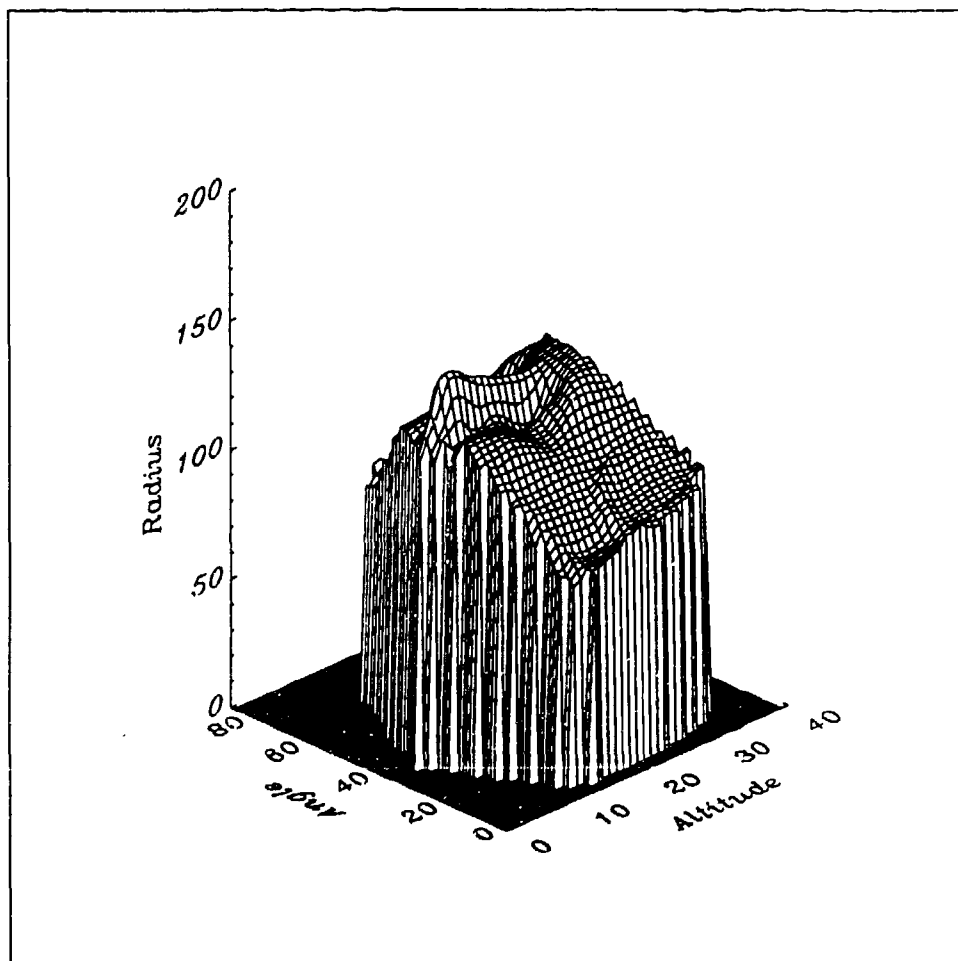
Subject 116 Kriged Surface



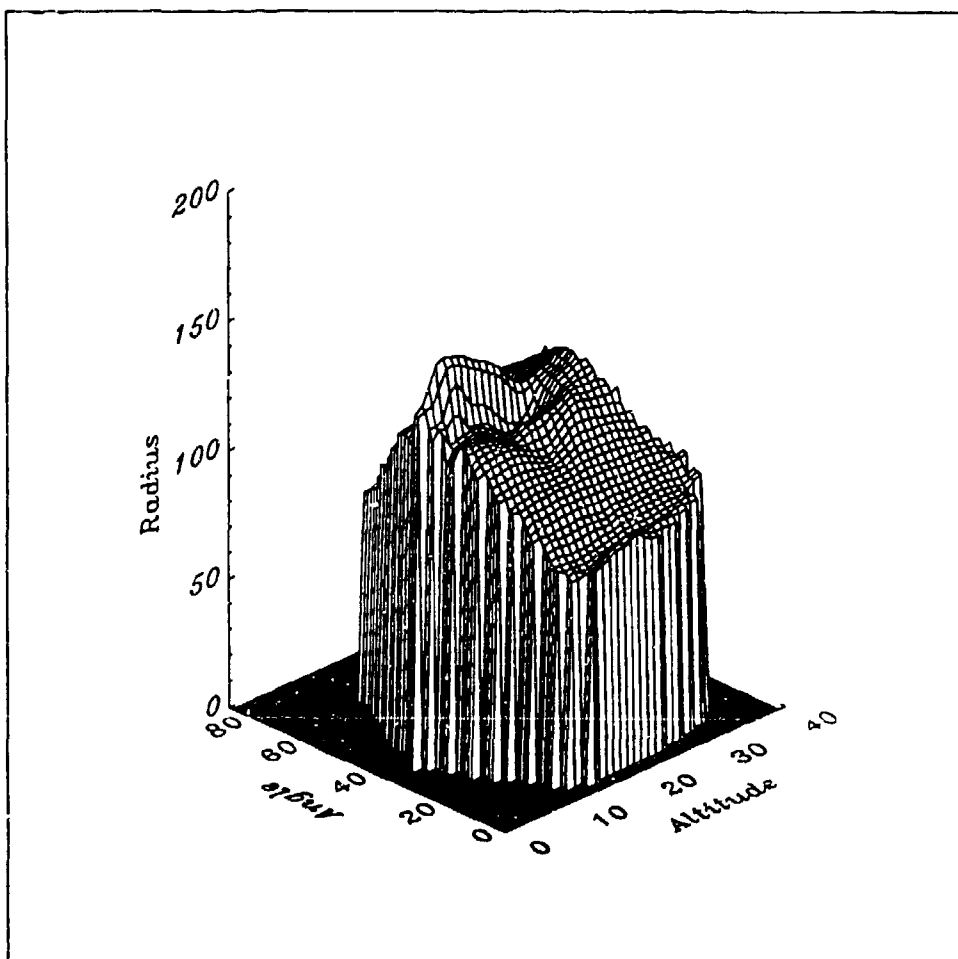
Subject 118 Kriged Surface



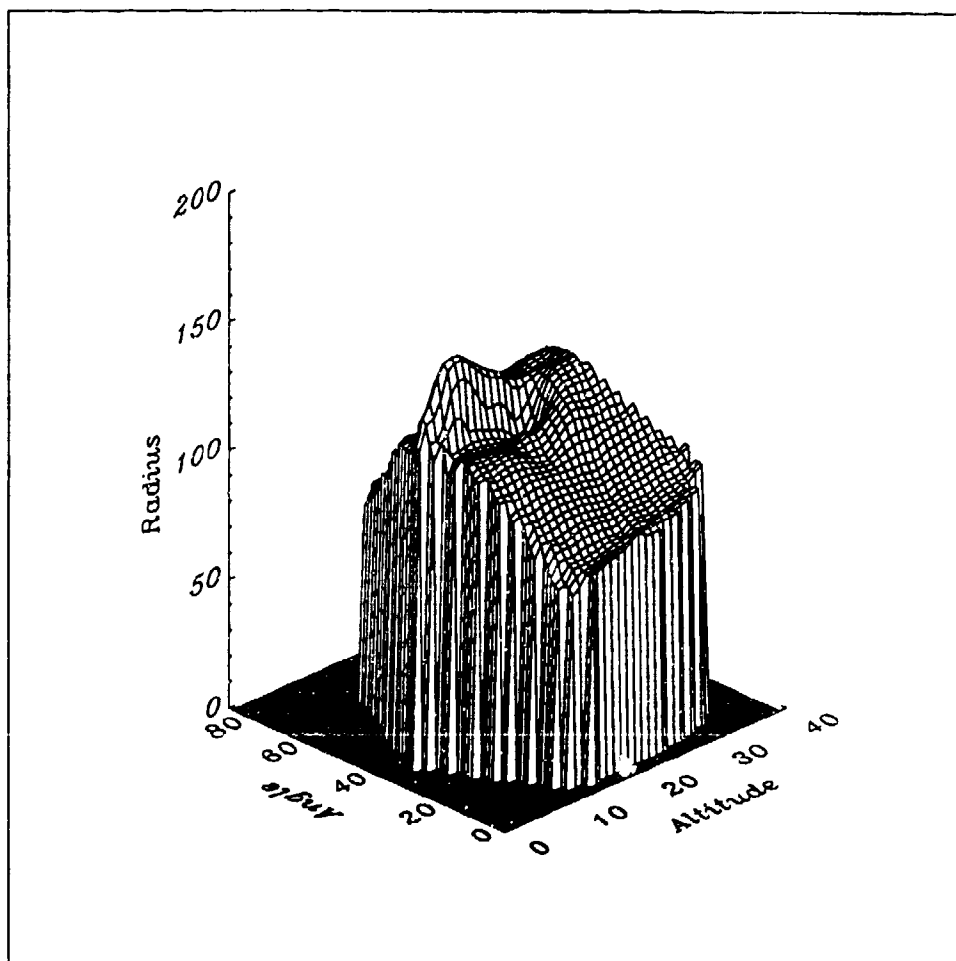
Subject 122 Kriged Surface



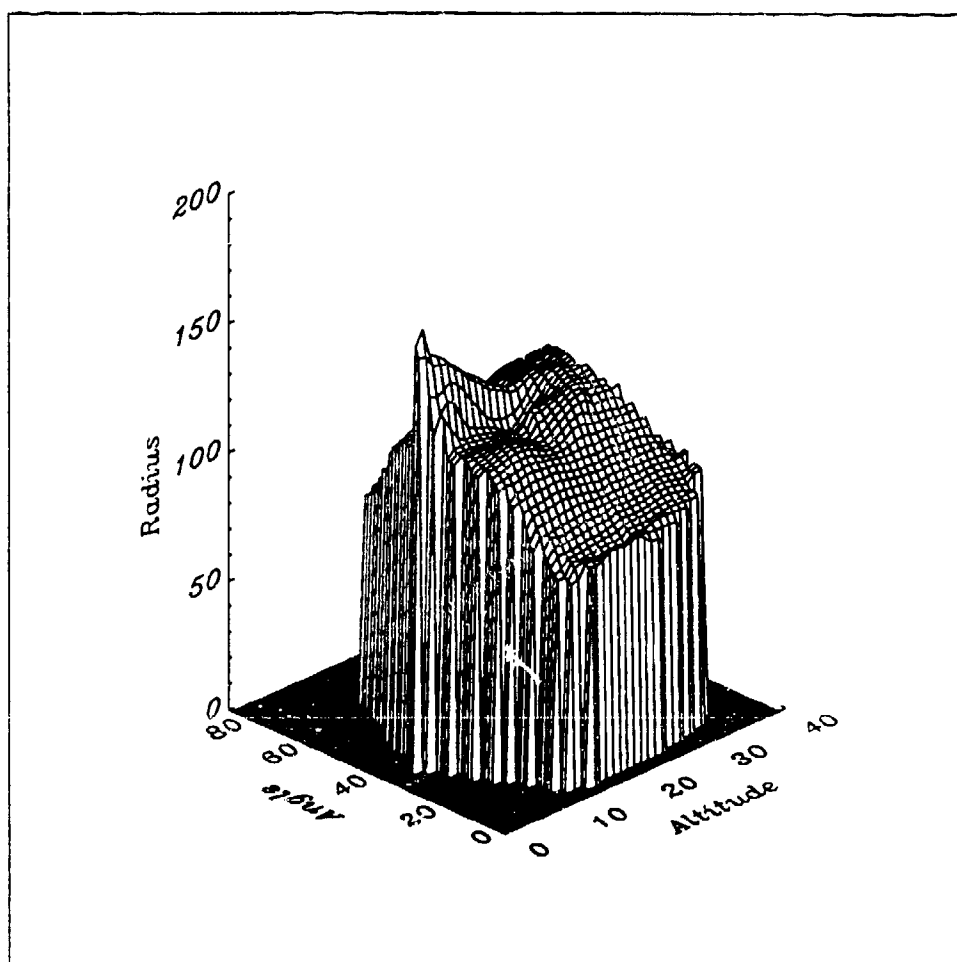
Subject 130 Kriged Surface



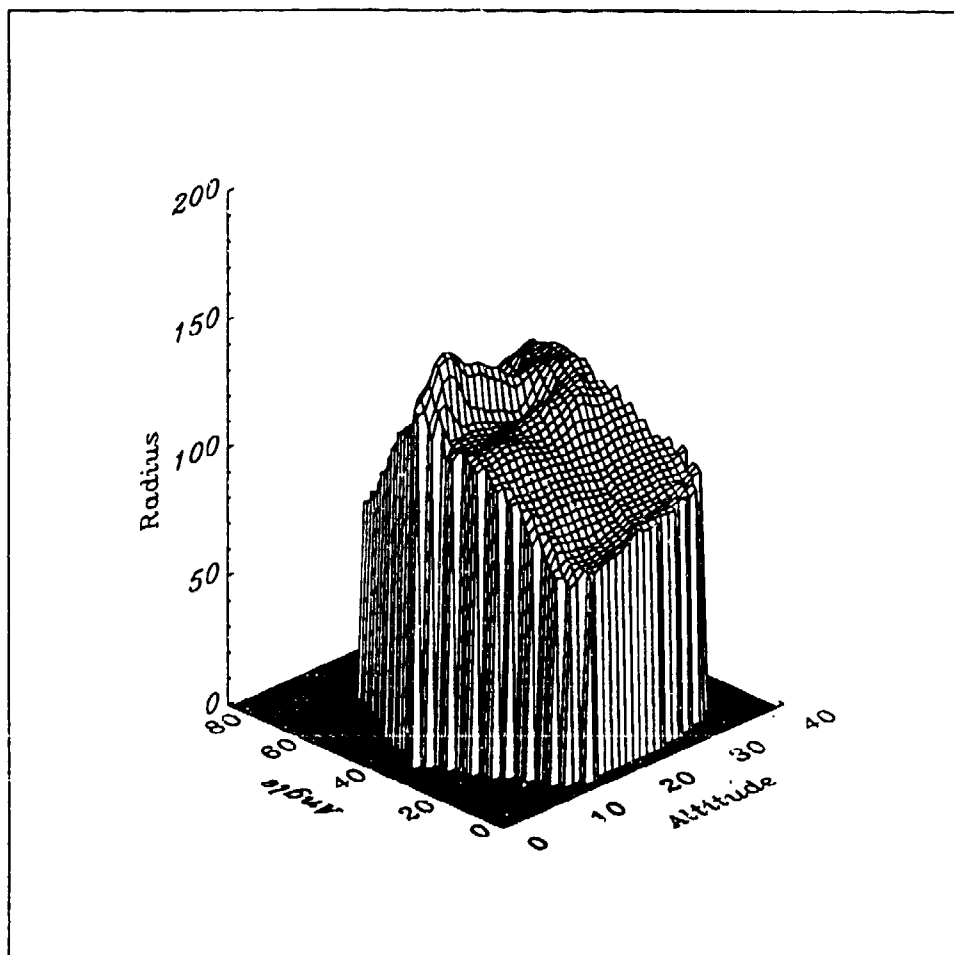
Subject 133 Kriged Surface



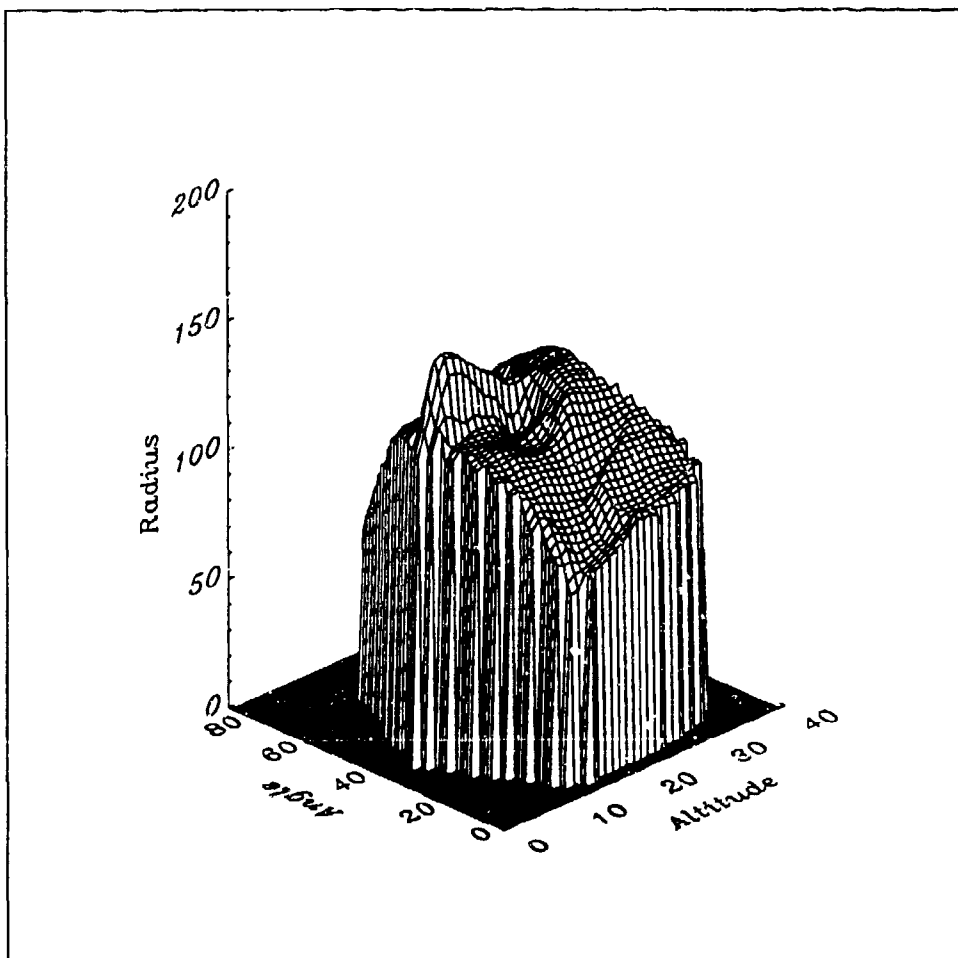
Subject 136 Kriged Surface



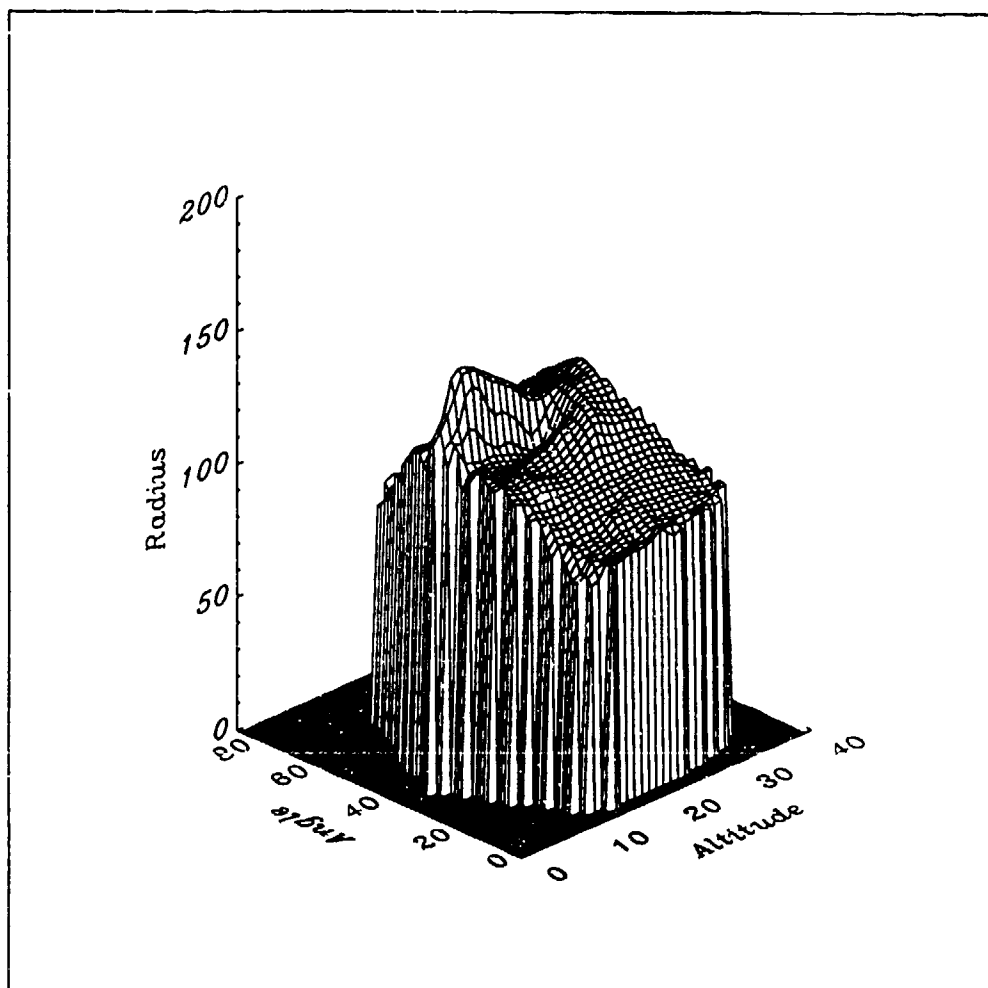
Subject 140 Kriged Surface



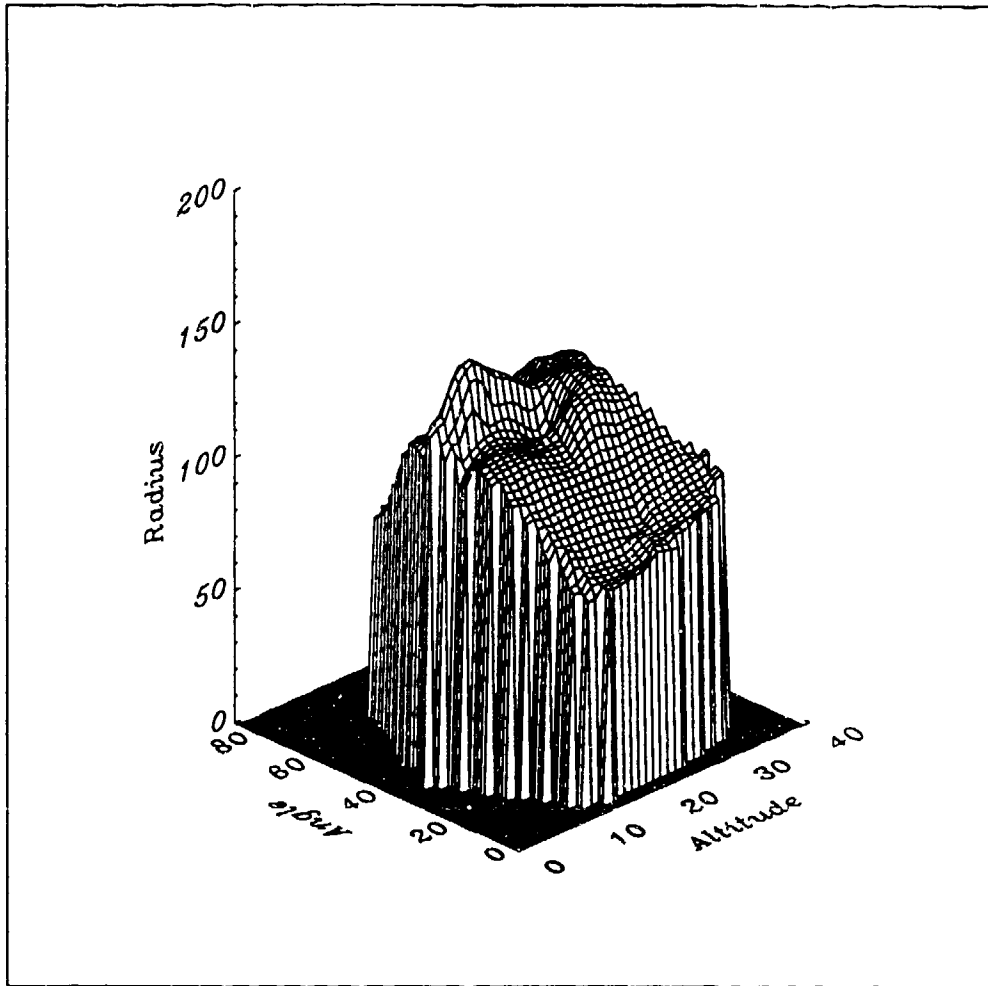
Subject 142 Kriged Surface



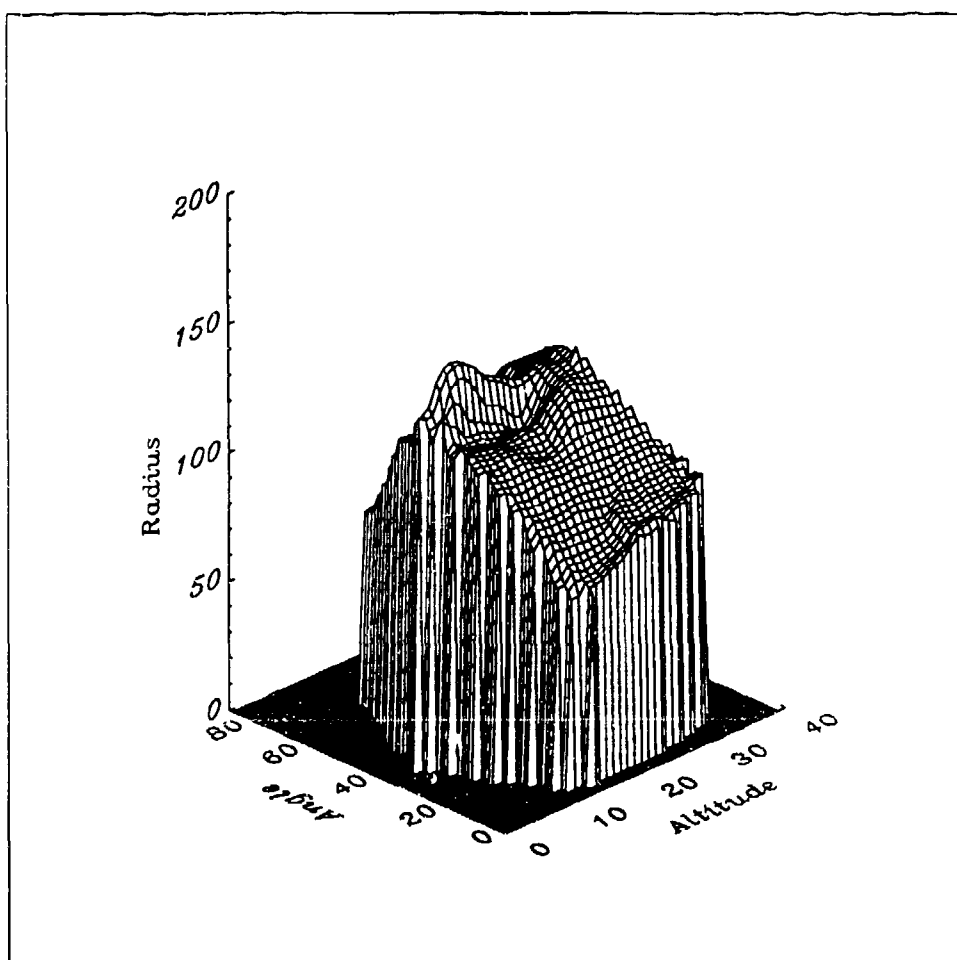
Subject 153 Kriged Surface



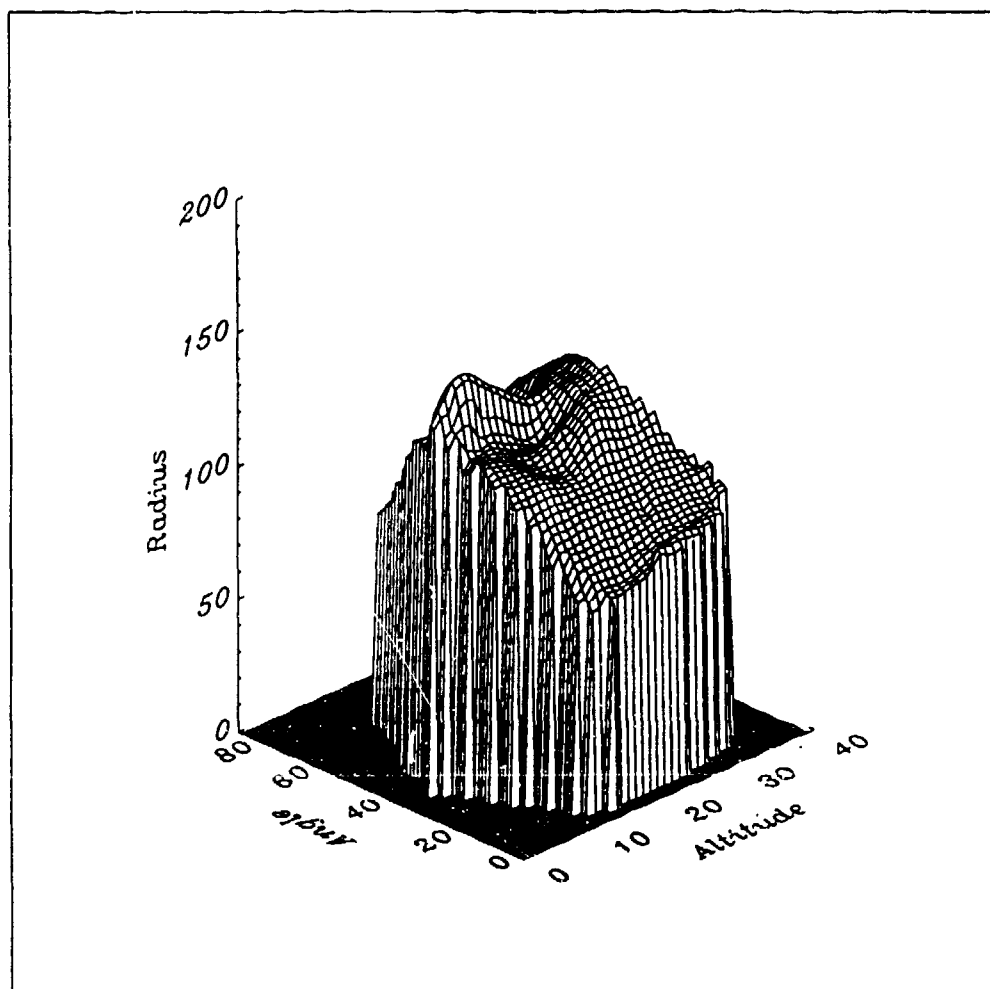
Subject 154 Kriged Surface



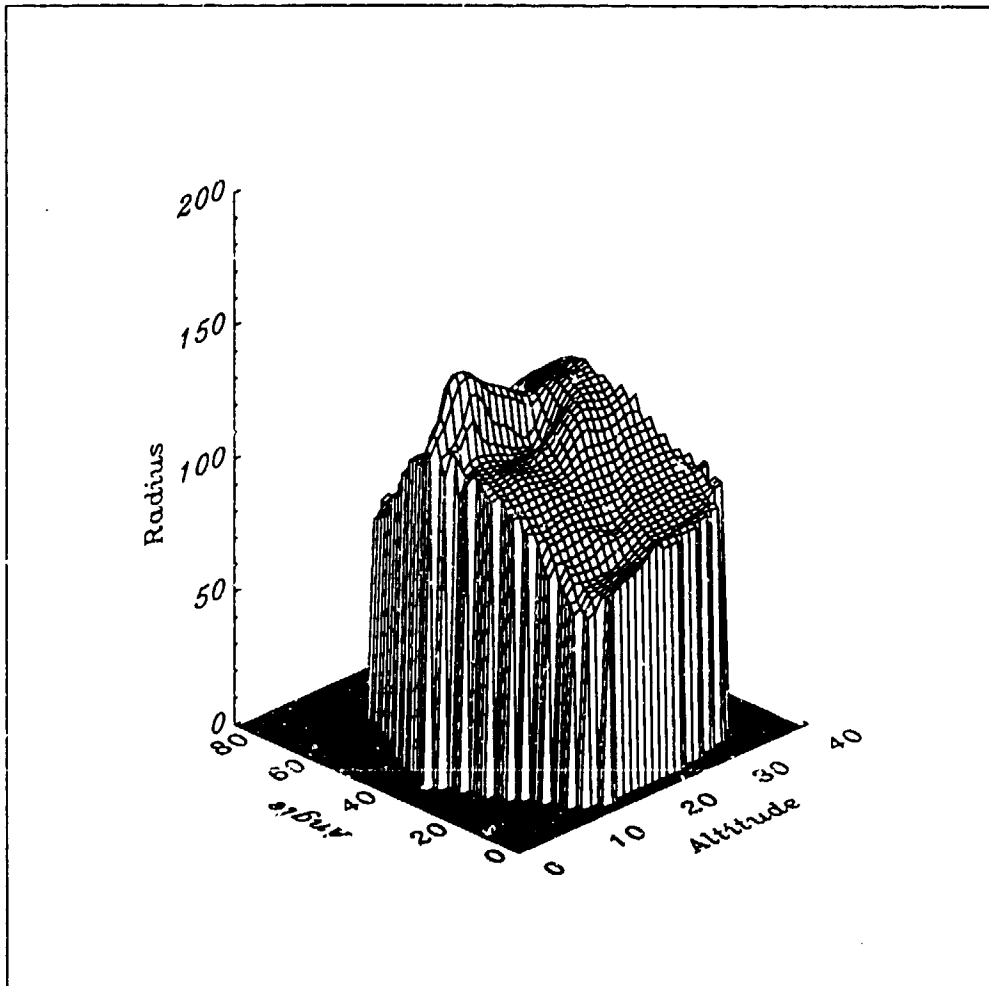
Subject 155 Kriged Surface



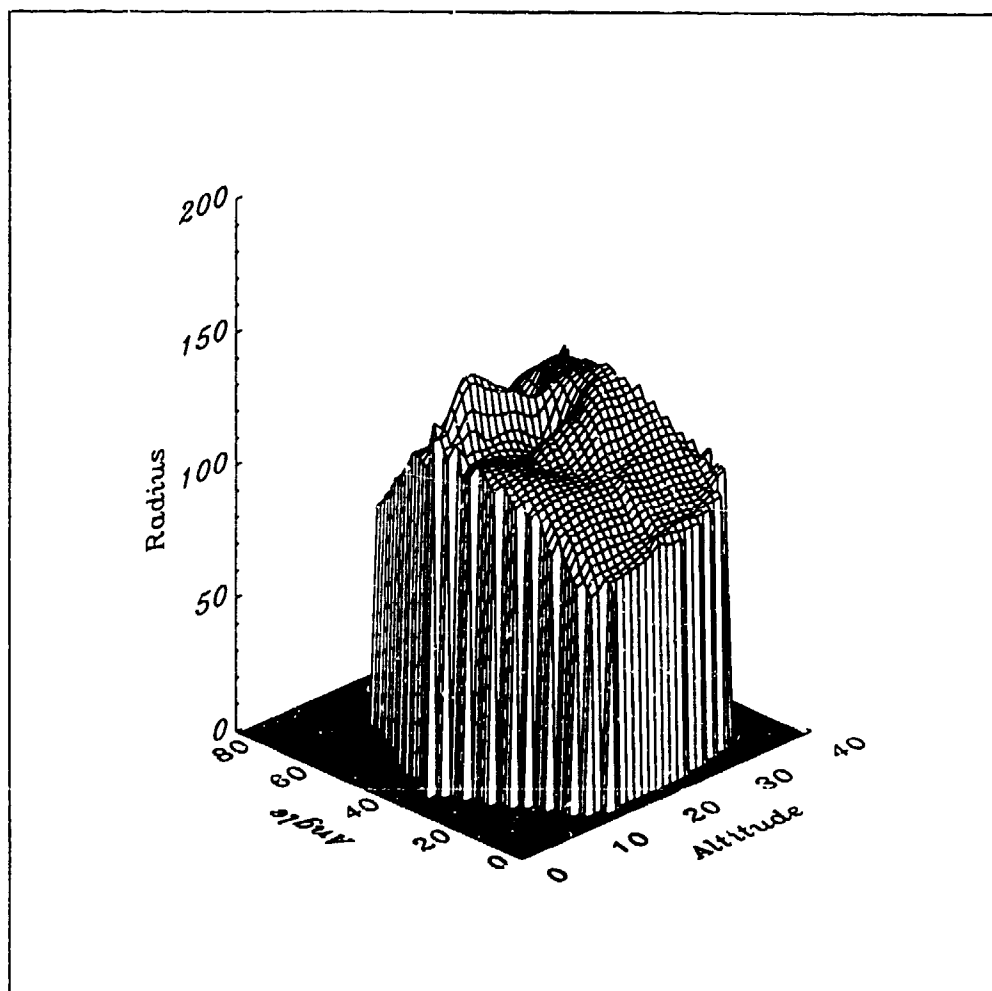
Subject 159 Kriged Surface



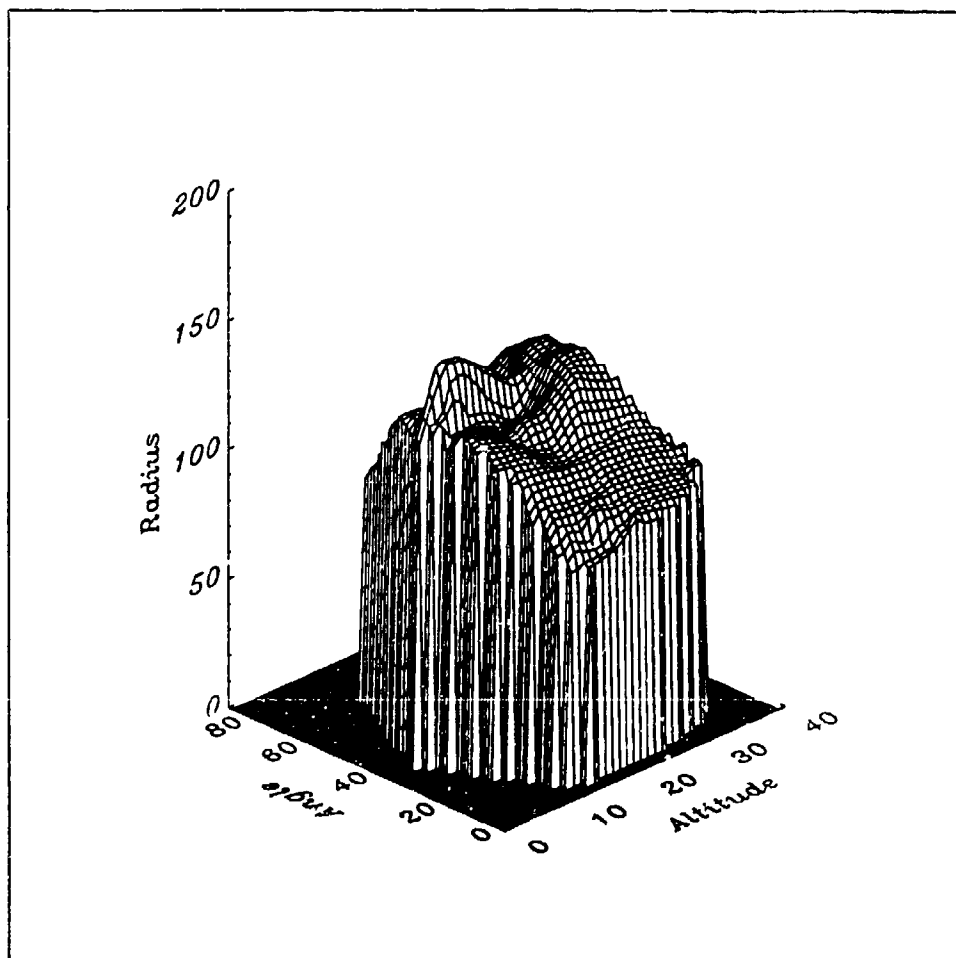
Subject 160 Kriged Surface



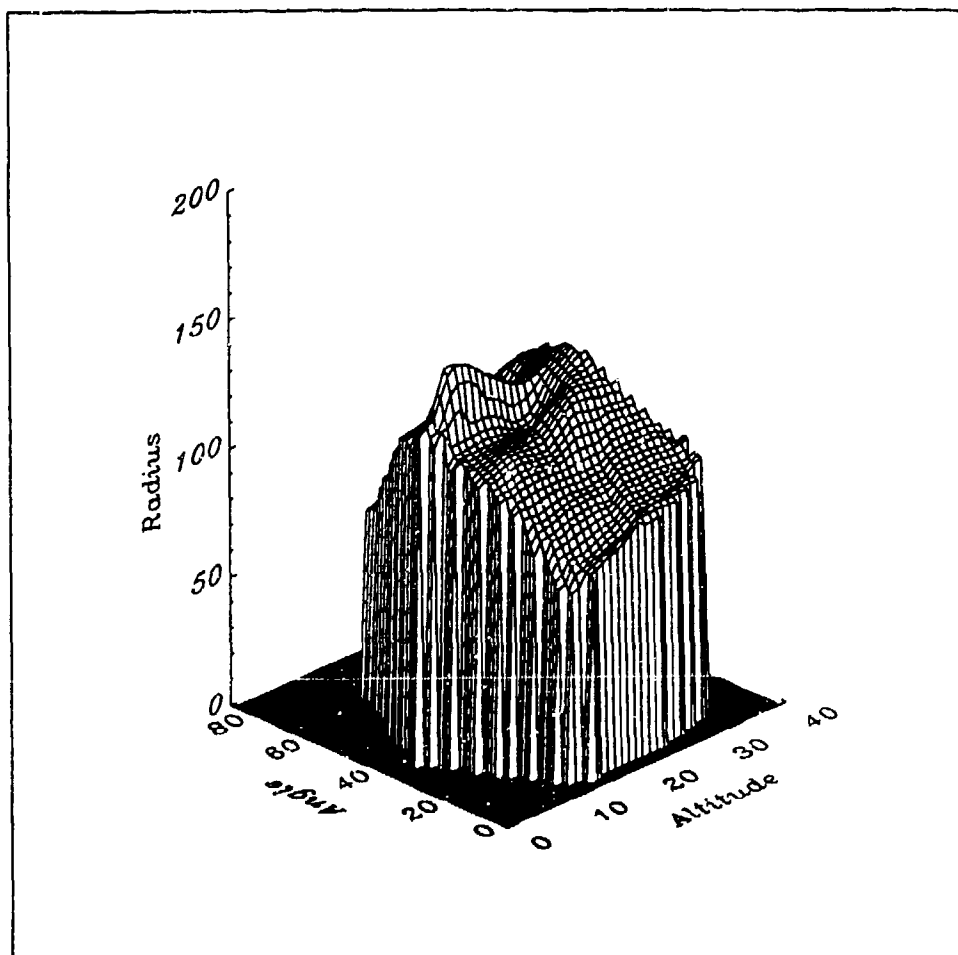
Subject 161 Kriged Surface



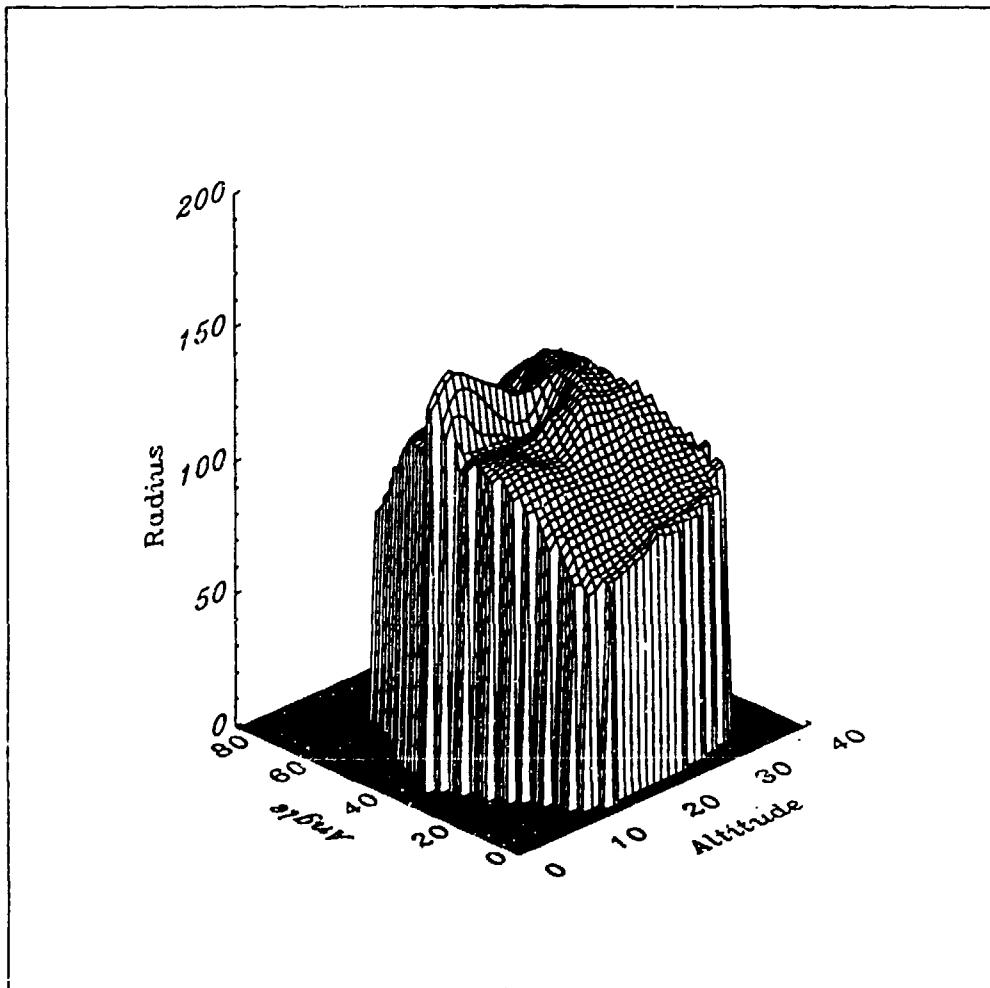
Subject 167 Kriged Surface



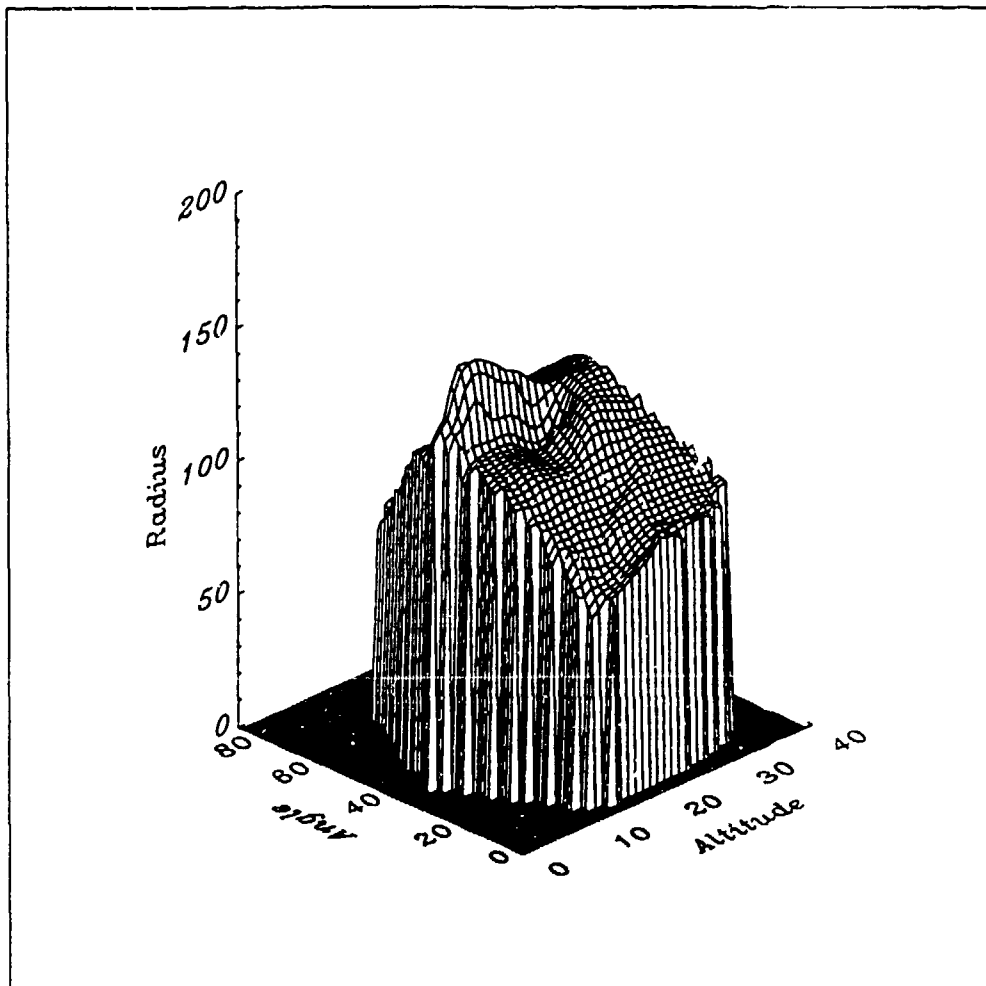
Subject 171 Kriged Surface



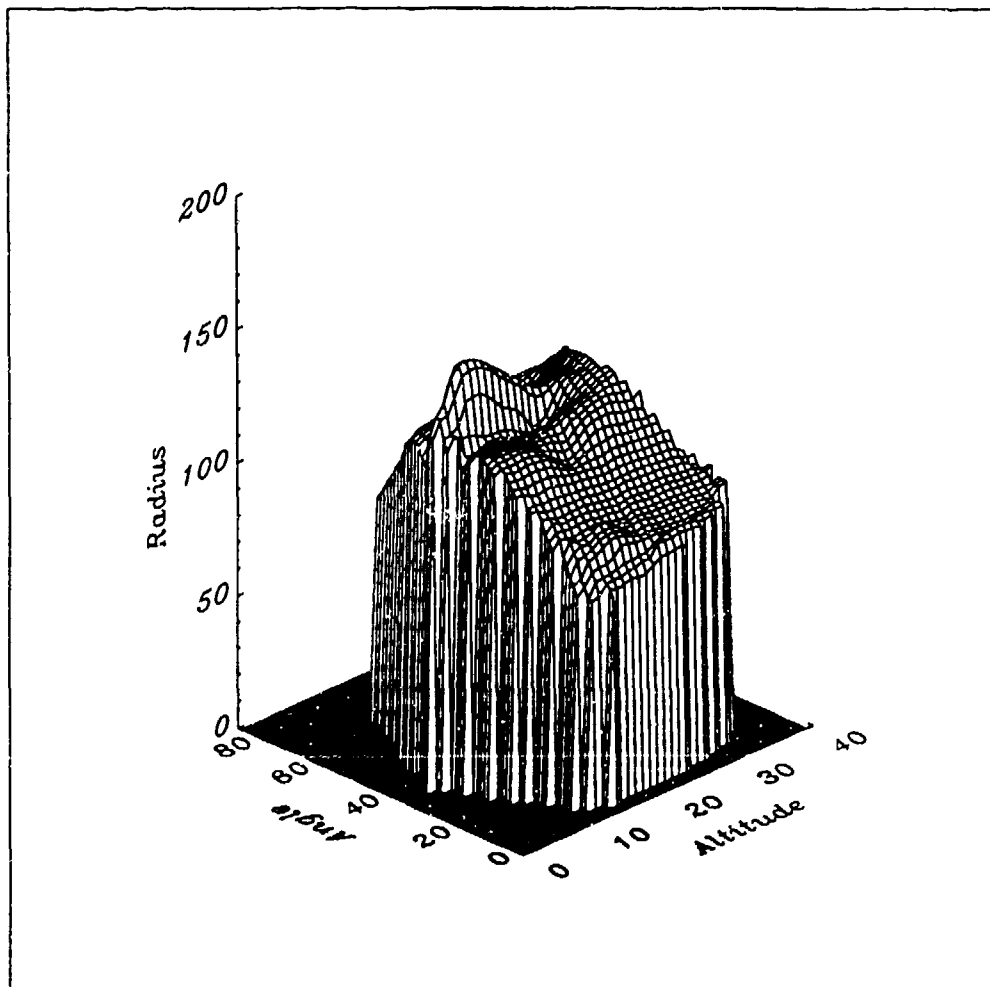
Subject 173 Kriged Surface



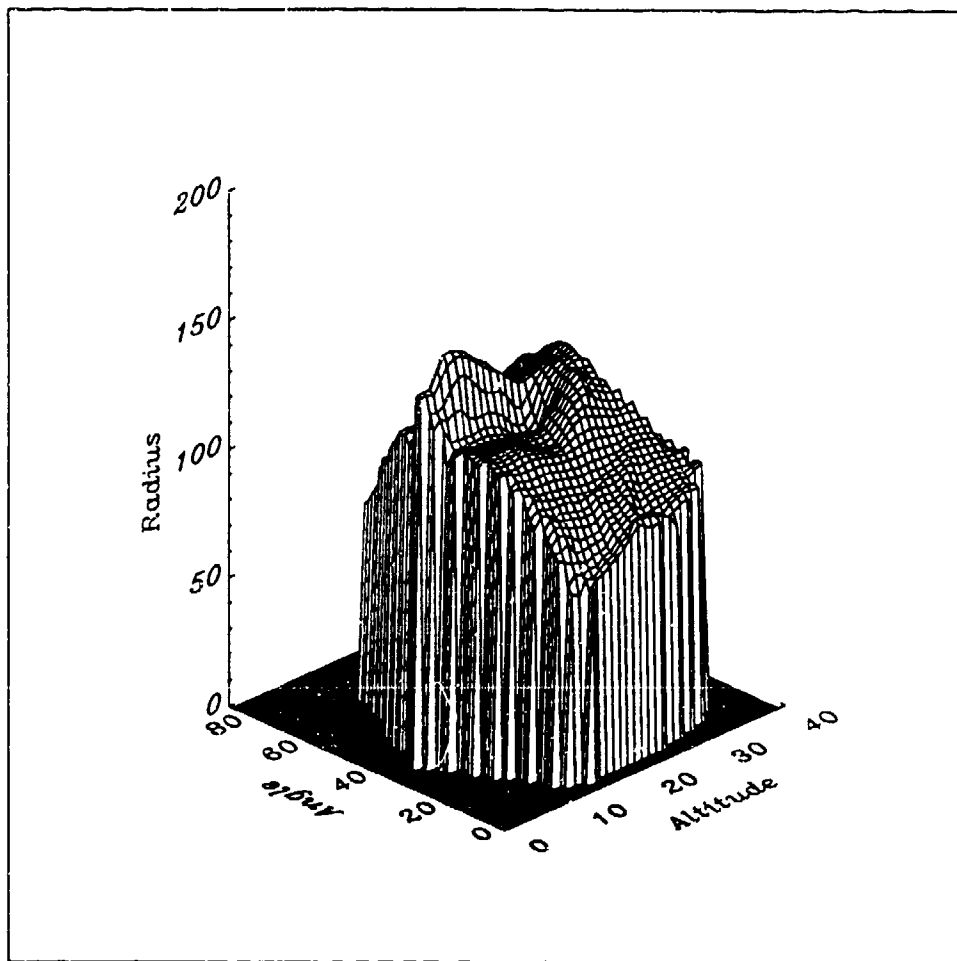
Subject 176 Kriged Surface



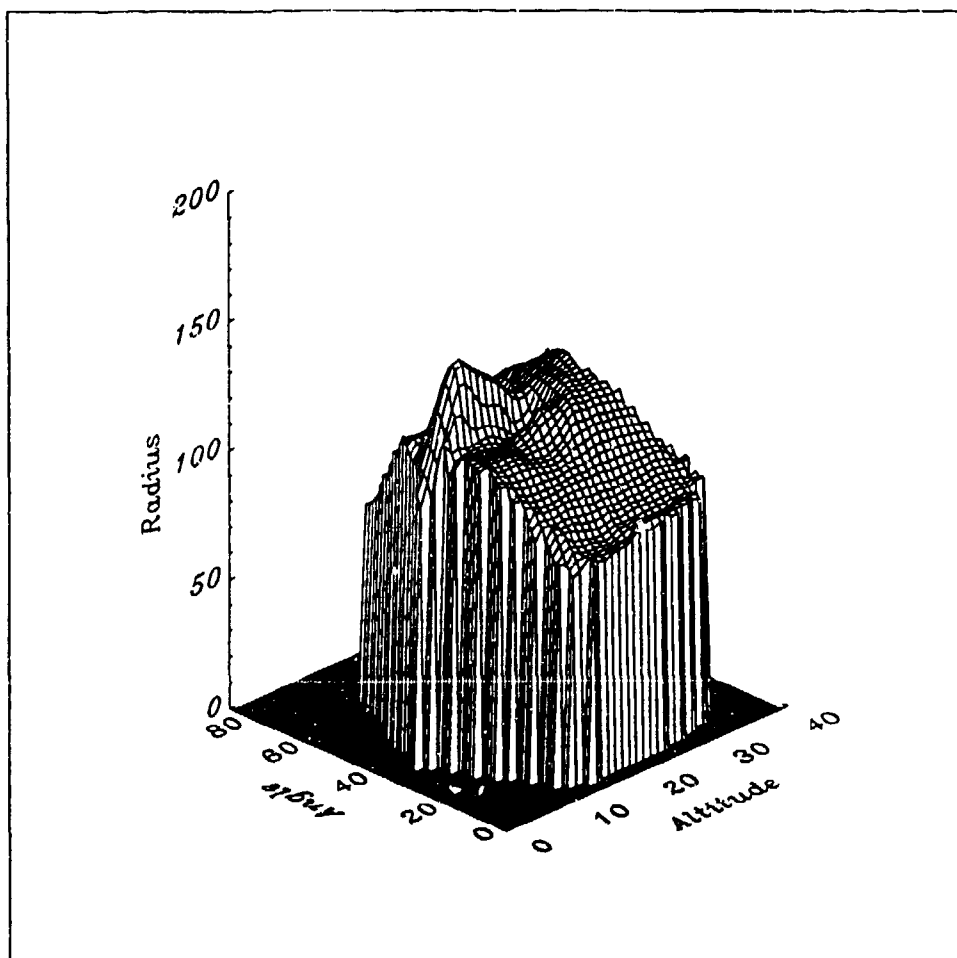
Subject 183 Kriged Surface



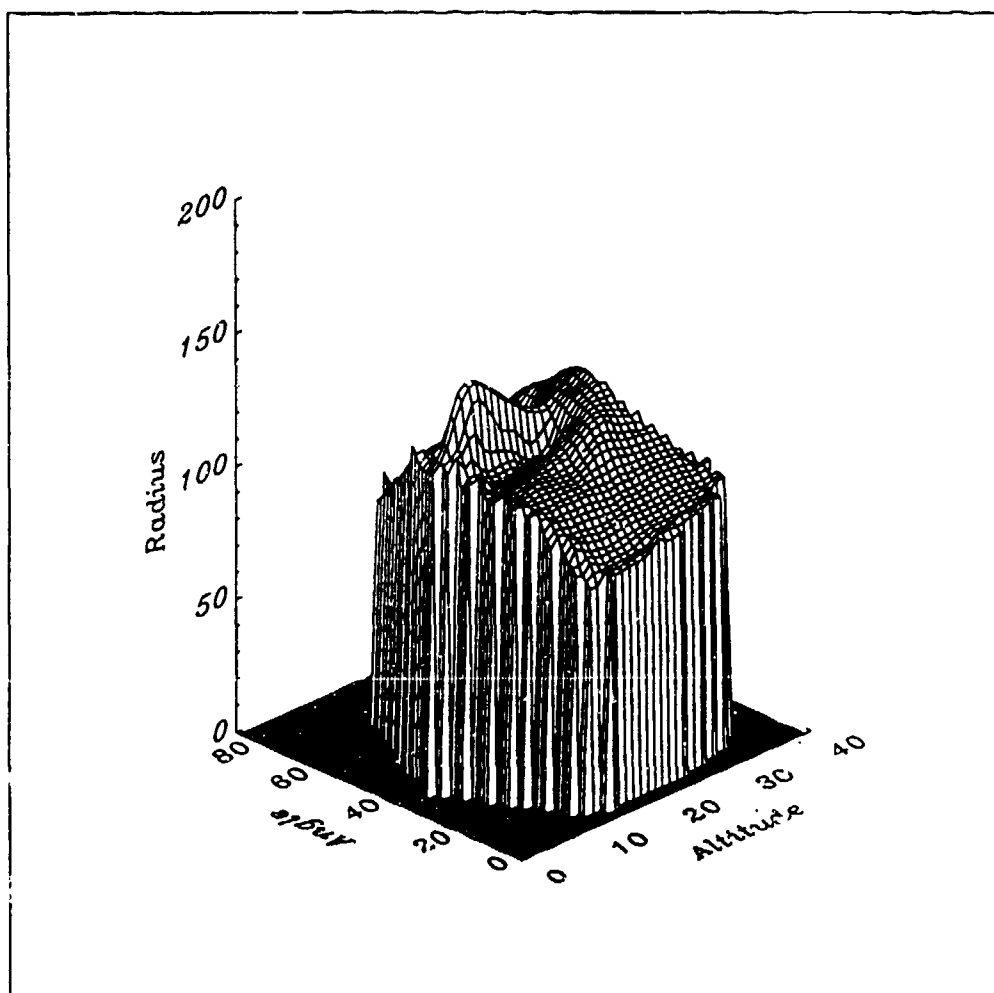
Subject 185 Kriged Surface



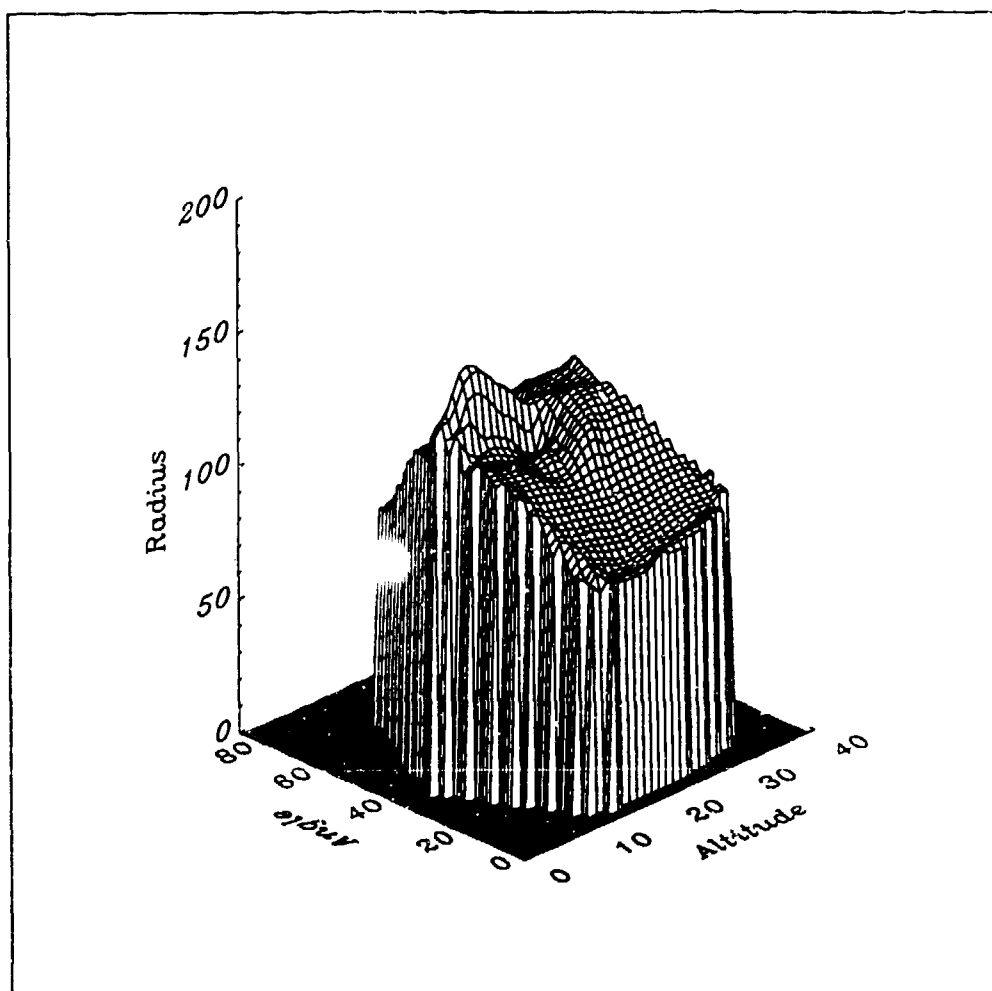
Subject 112 Kriged Surface



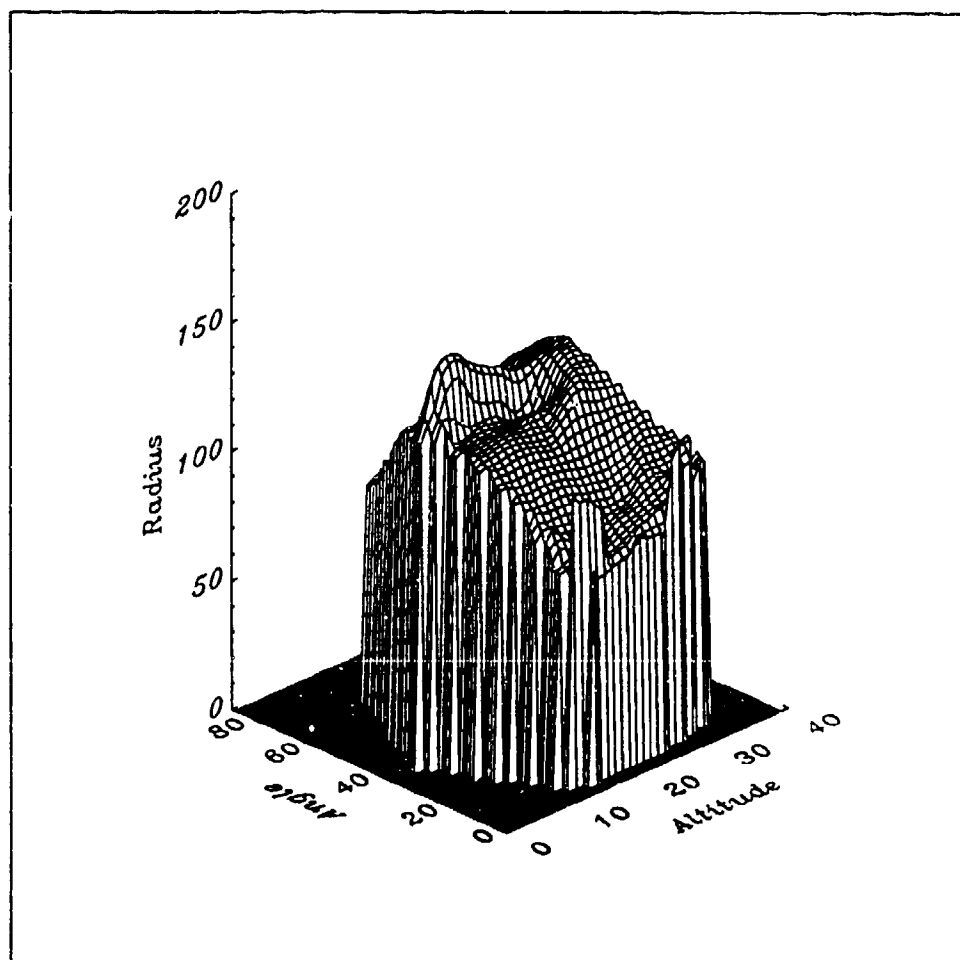
Subject 141 Kriged Surface



Subject 152 Krige Surface



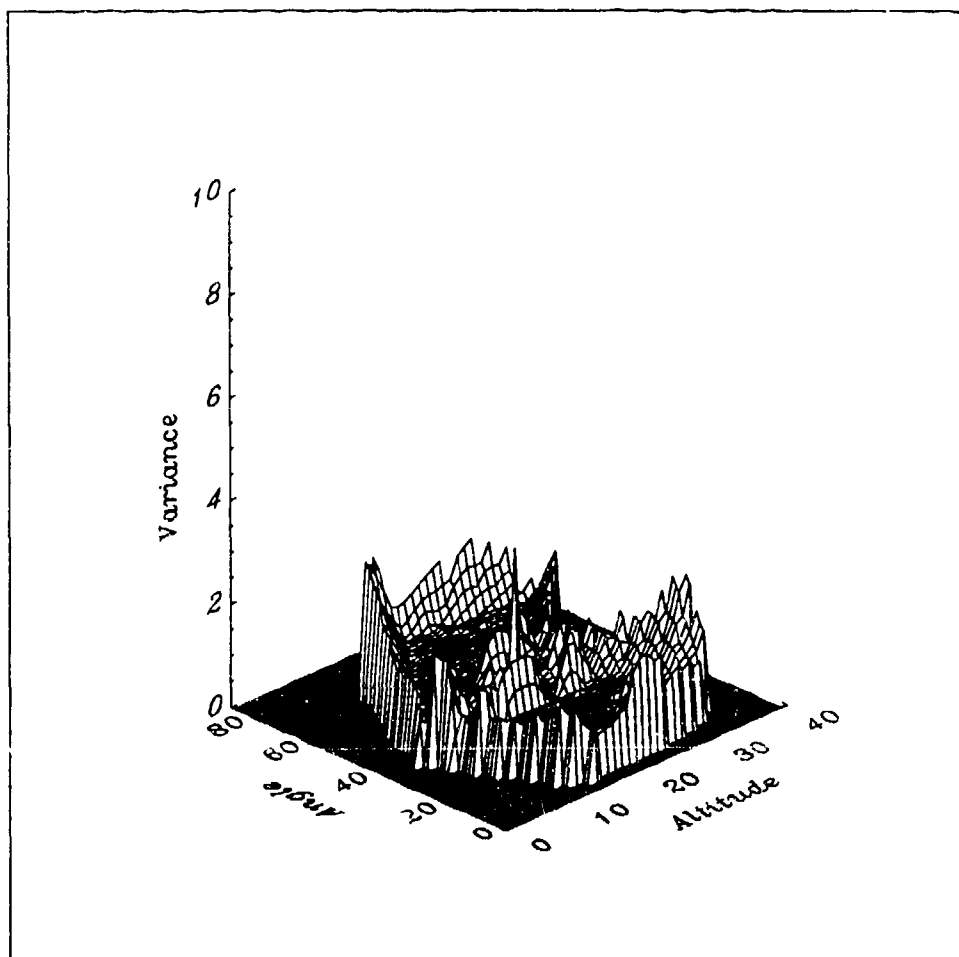
Surface 15- Kriged Surface



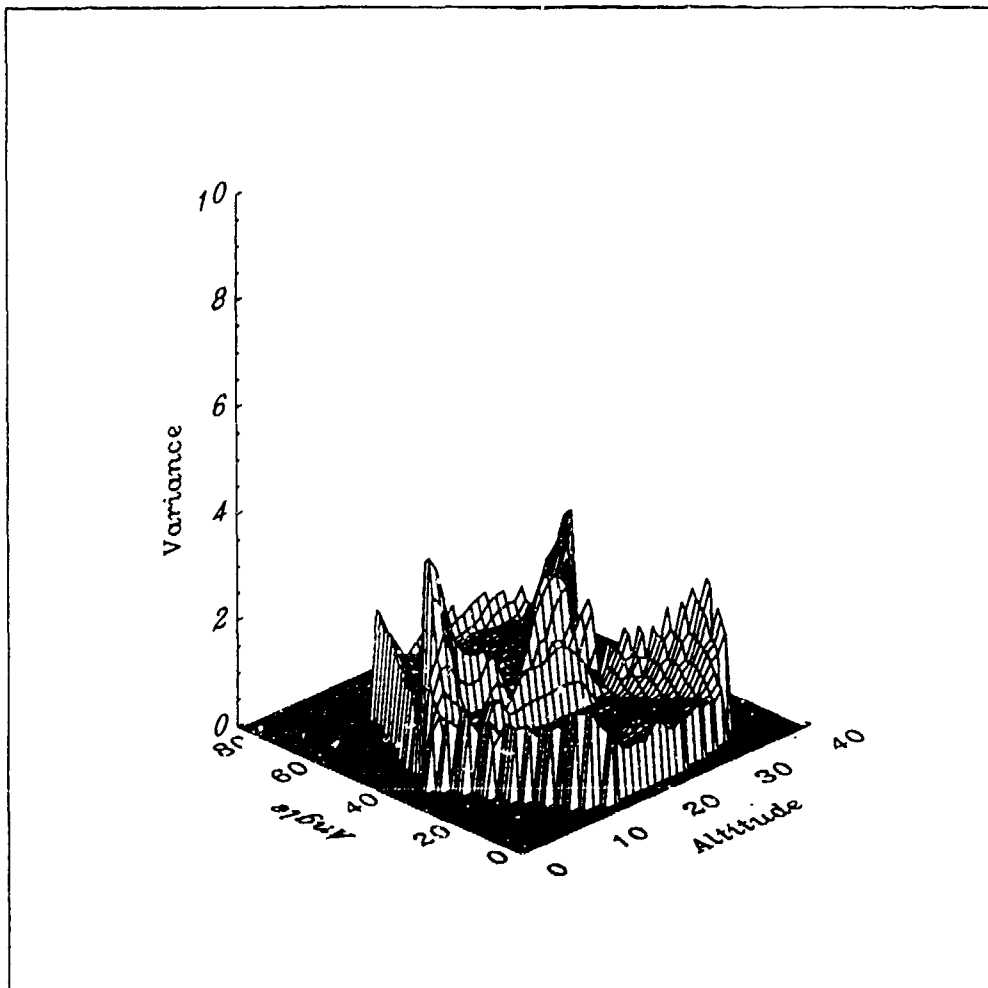
Subject 199 Kriged Surface

### *Facial Surface Estimation Variances*

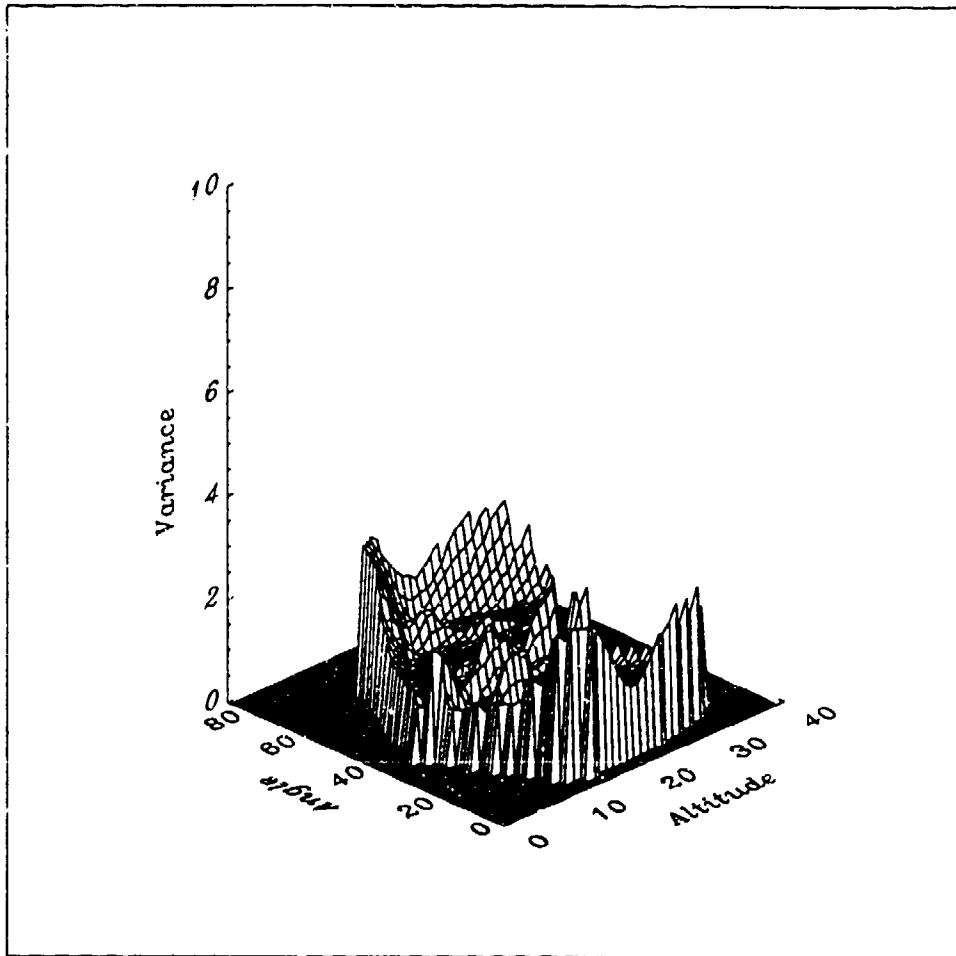
This section provides the kriging variances corresponding to the figures displayed in the previous sections.



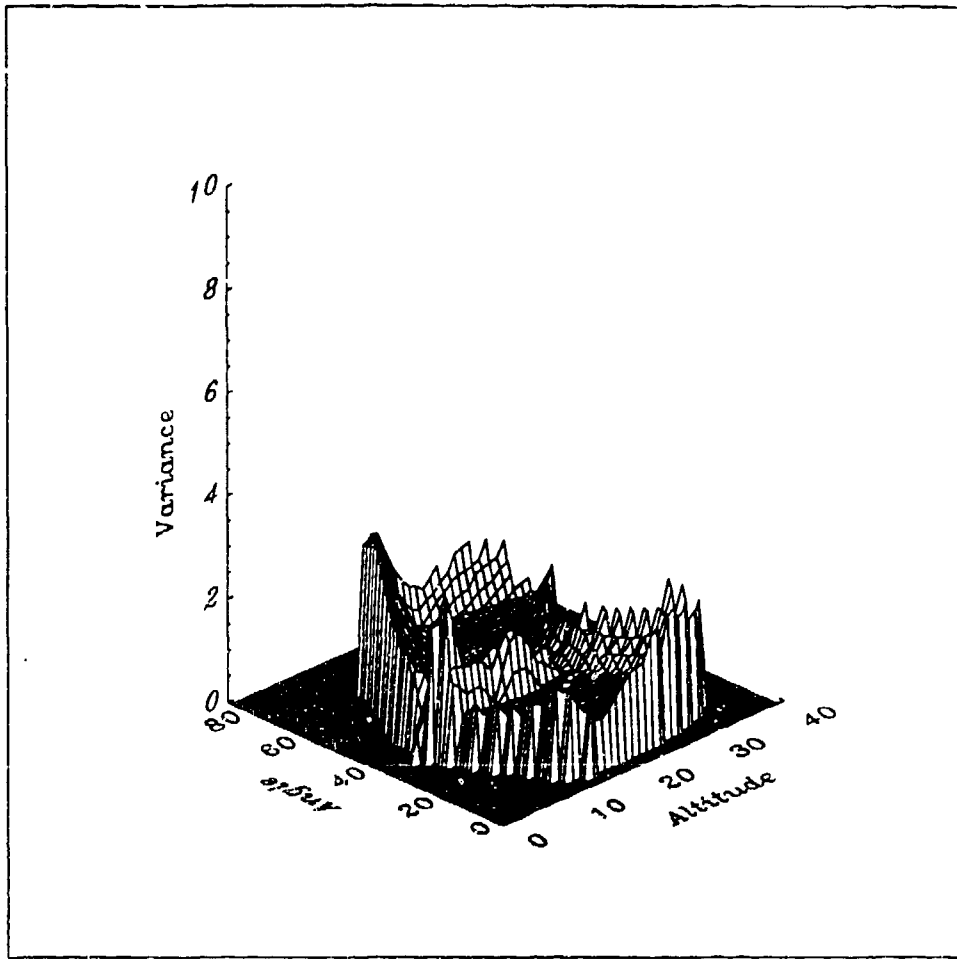
Estimation Variances for Subject 09



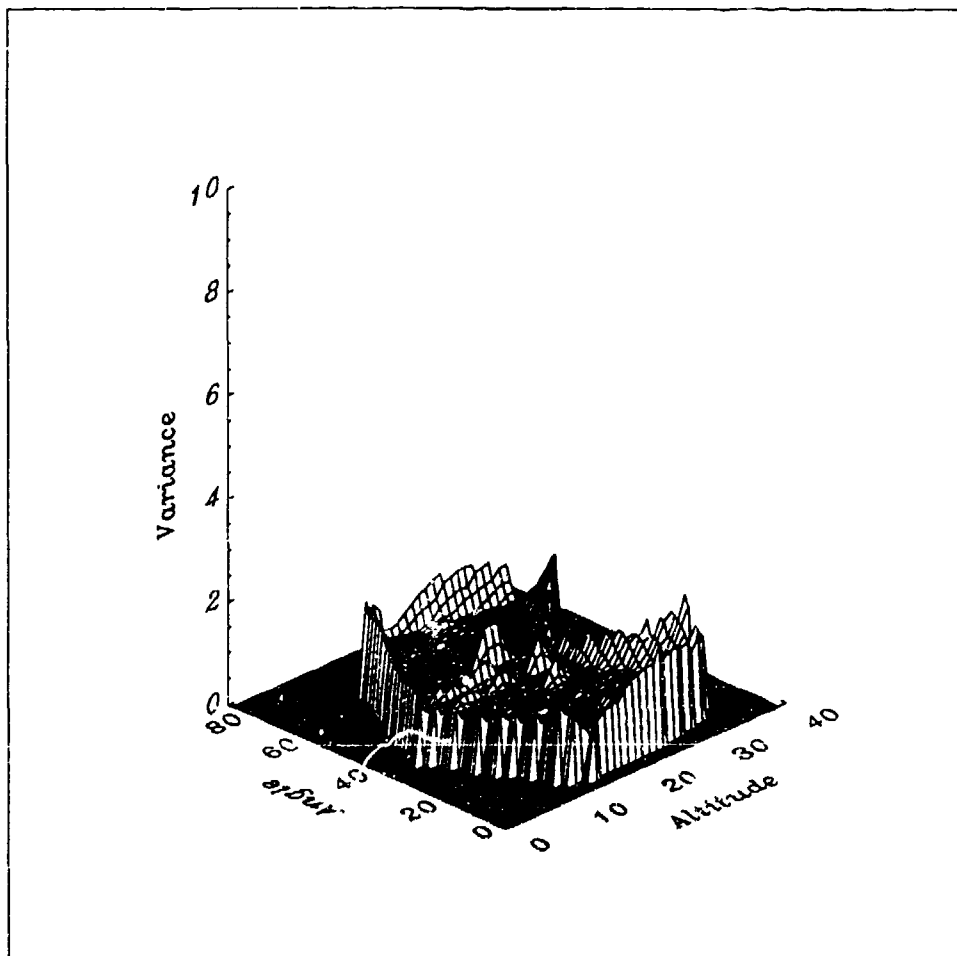
Estimation Variances for Subject 10



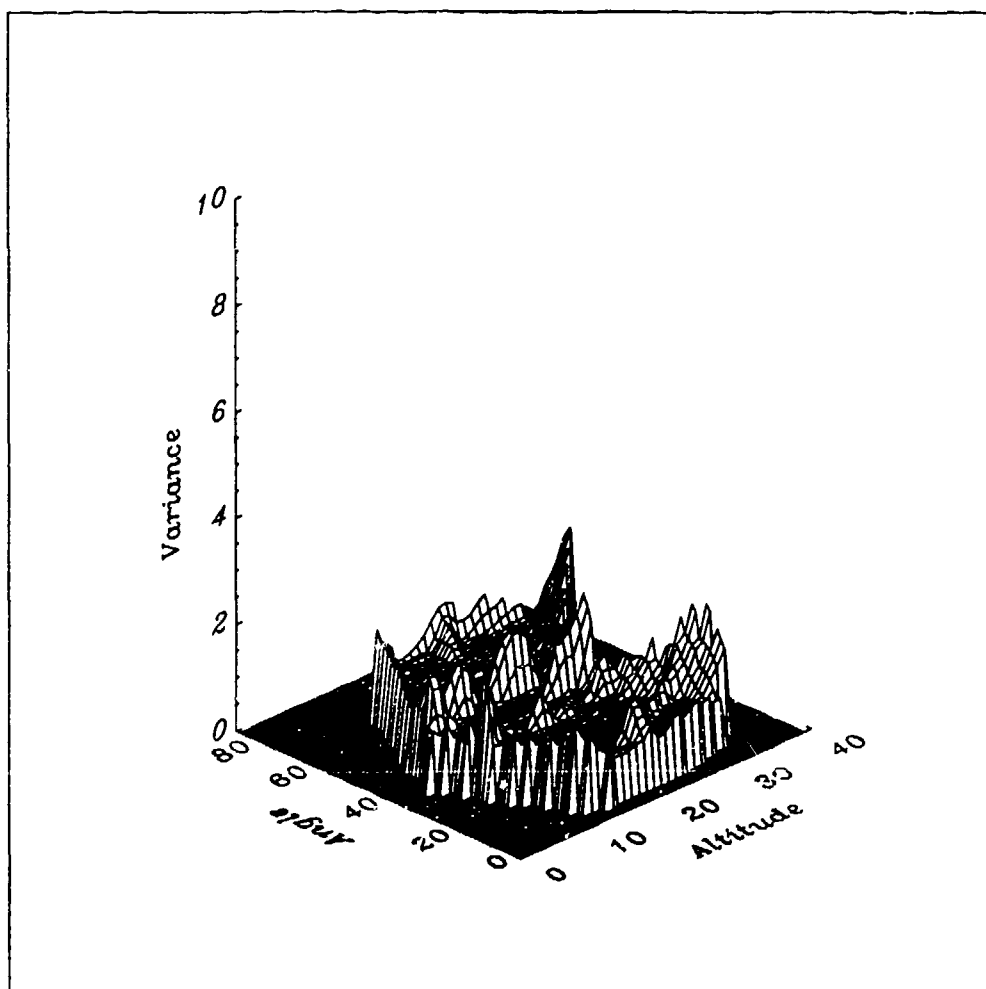
Estimation Variances for Subject 60



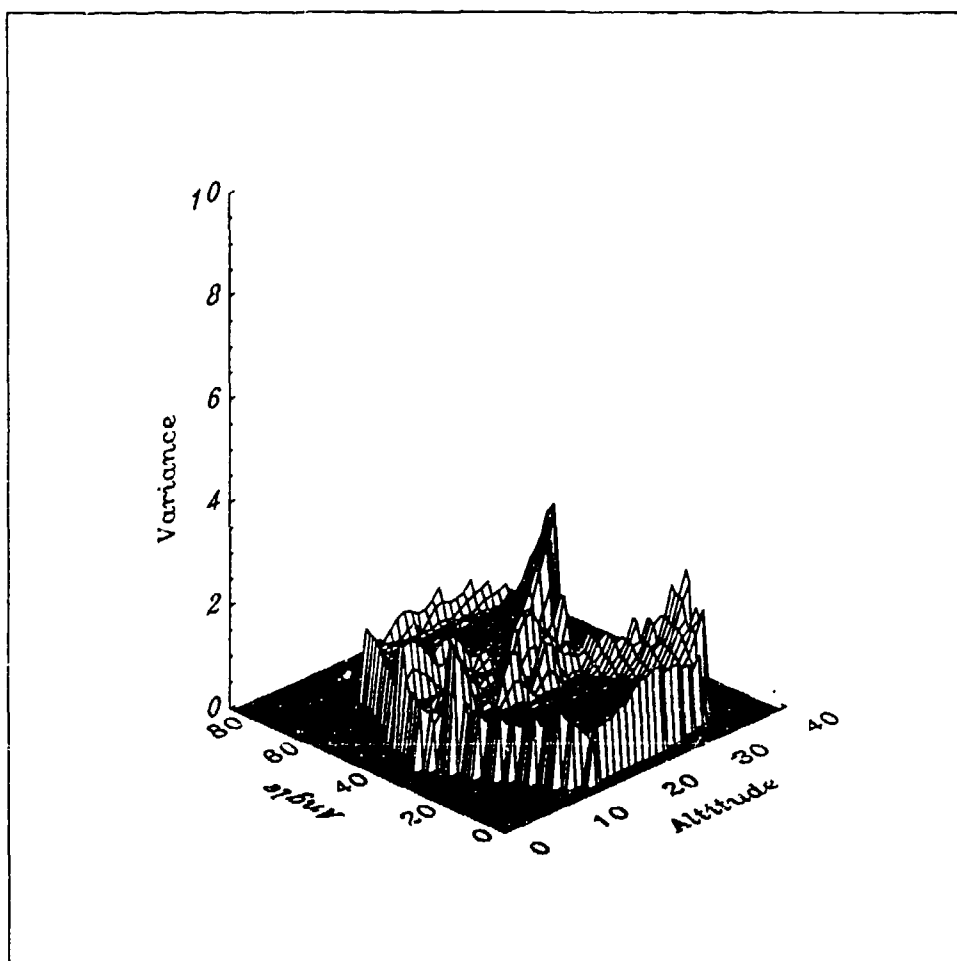
Estimation Variances for Subject 68



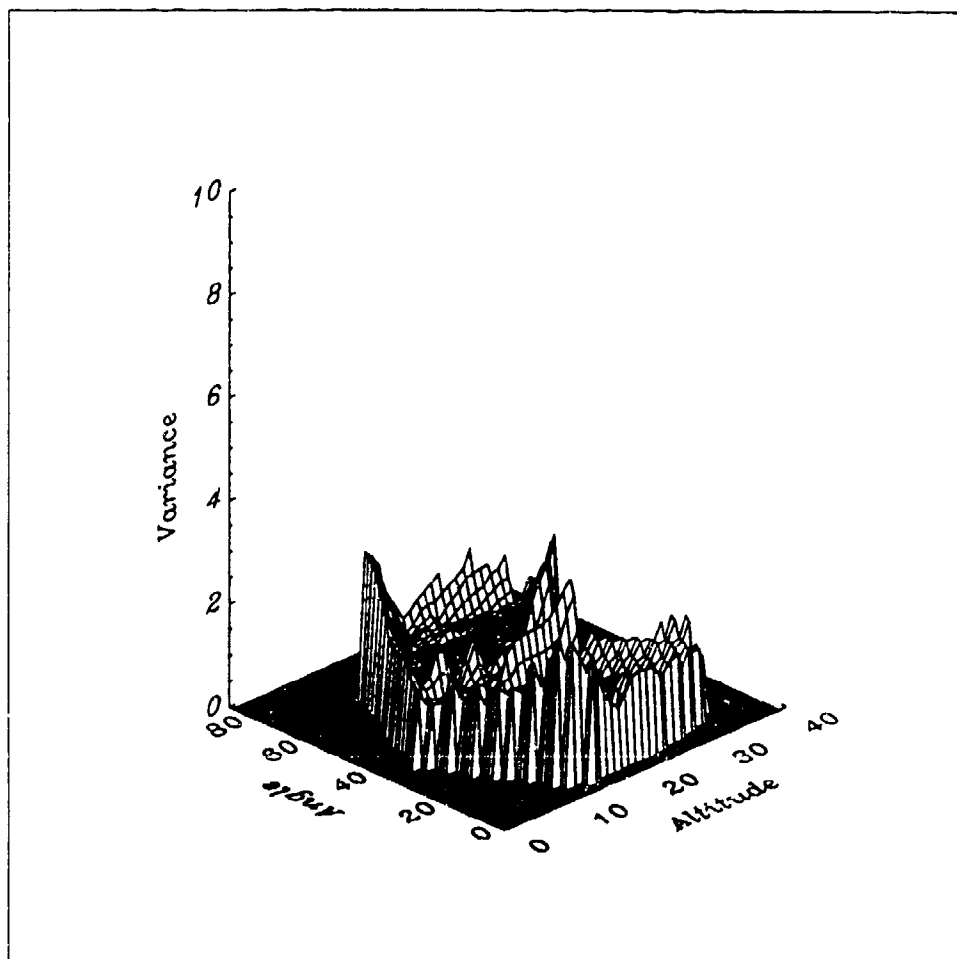
Estimation Variances for Subject 114



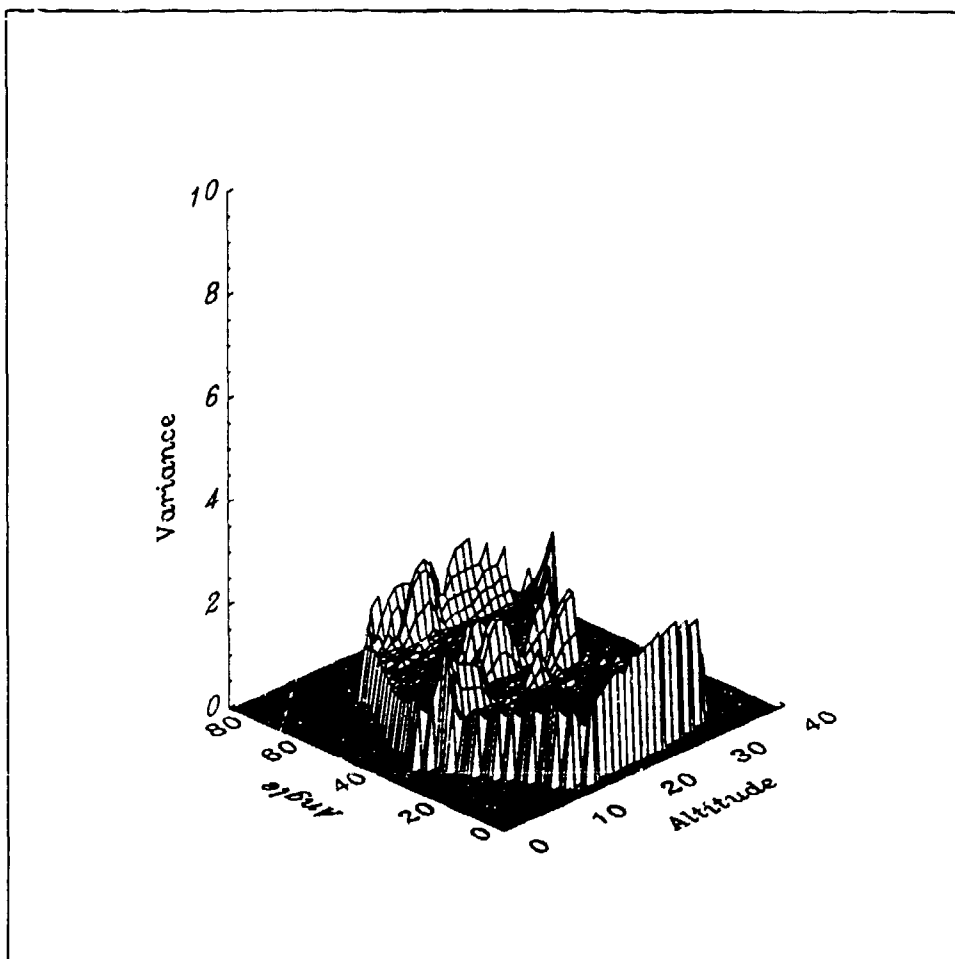
Estimation Variances for Subject 116



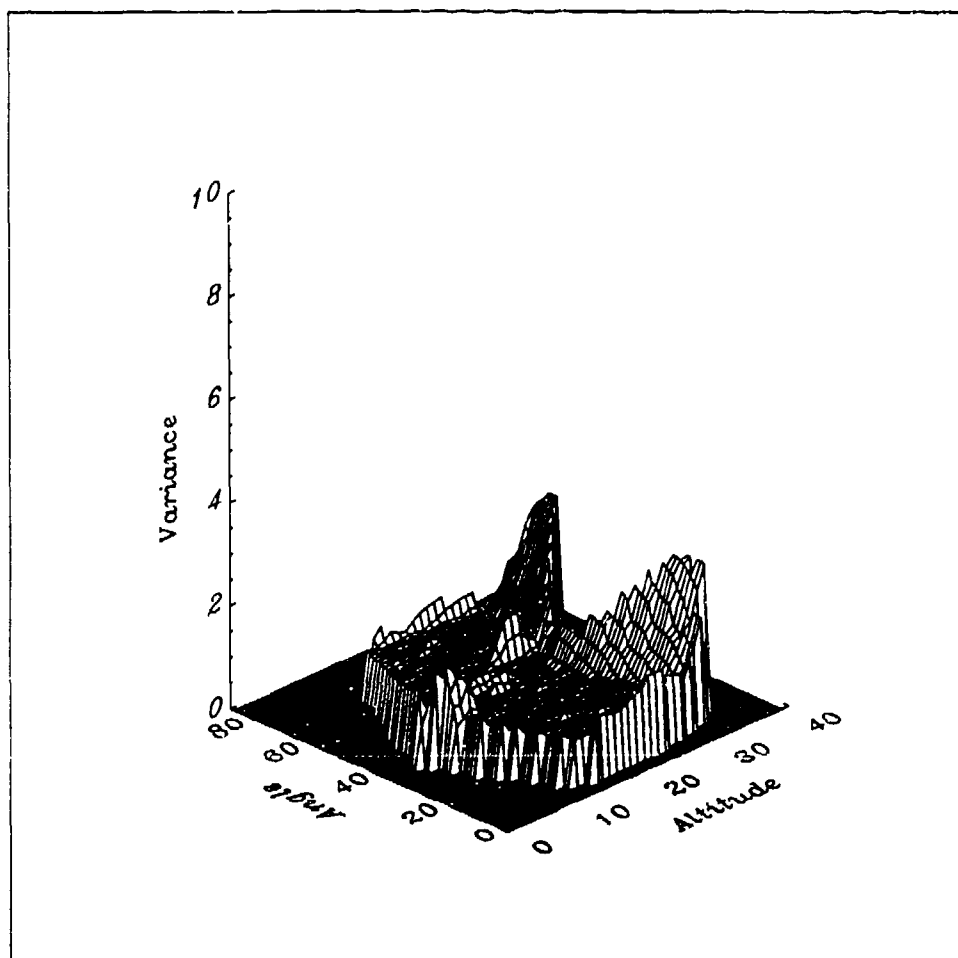
Estimation Variances for Subject 118



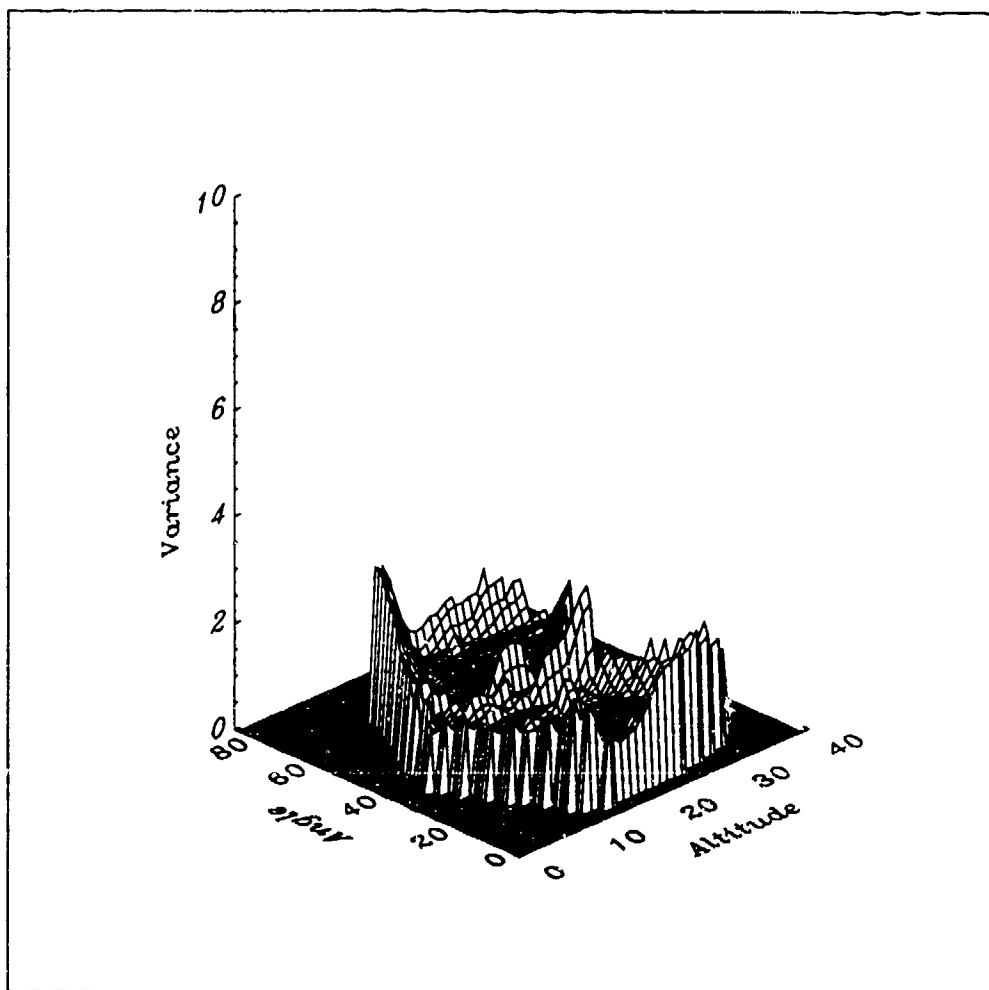
Estimation Variances for Subject 122



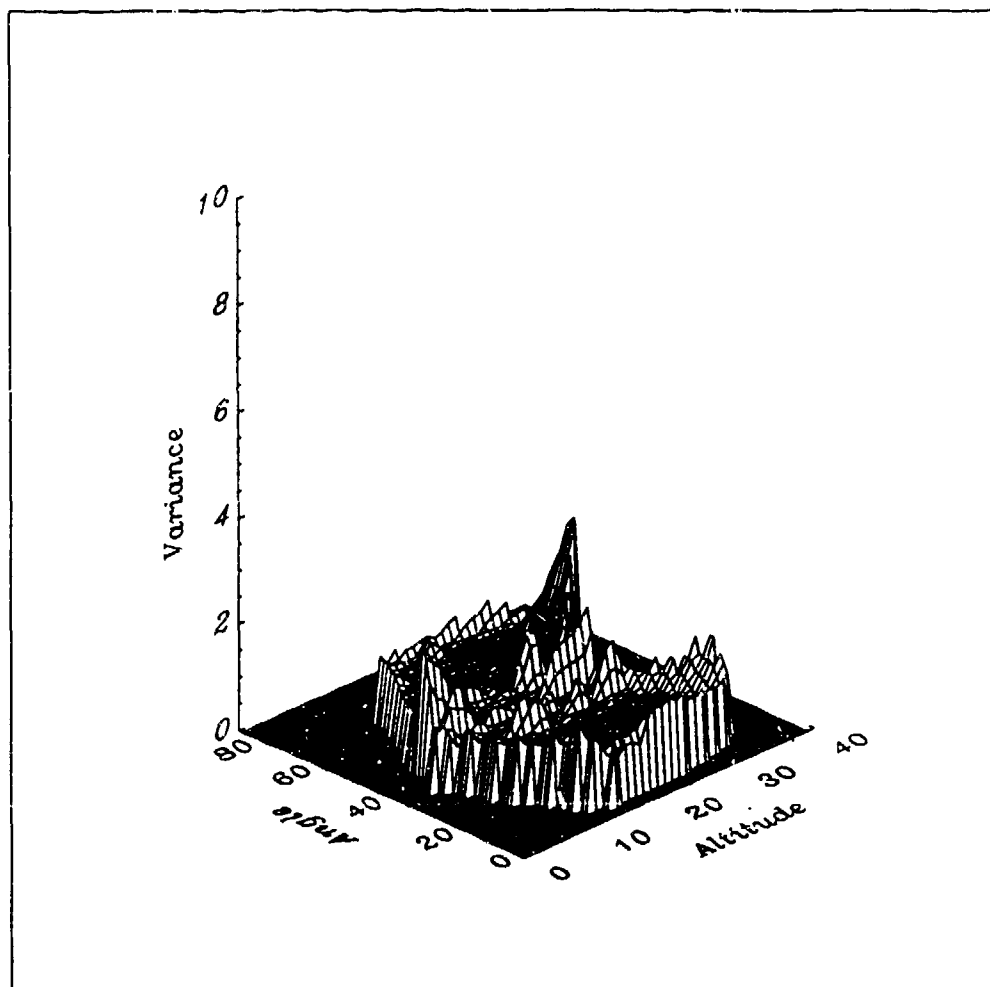
Estimation Variances for Subject 130



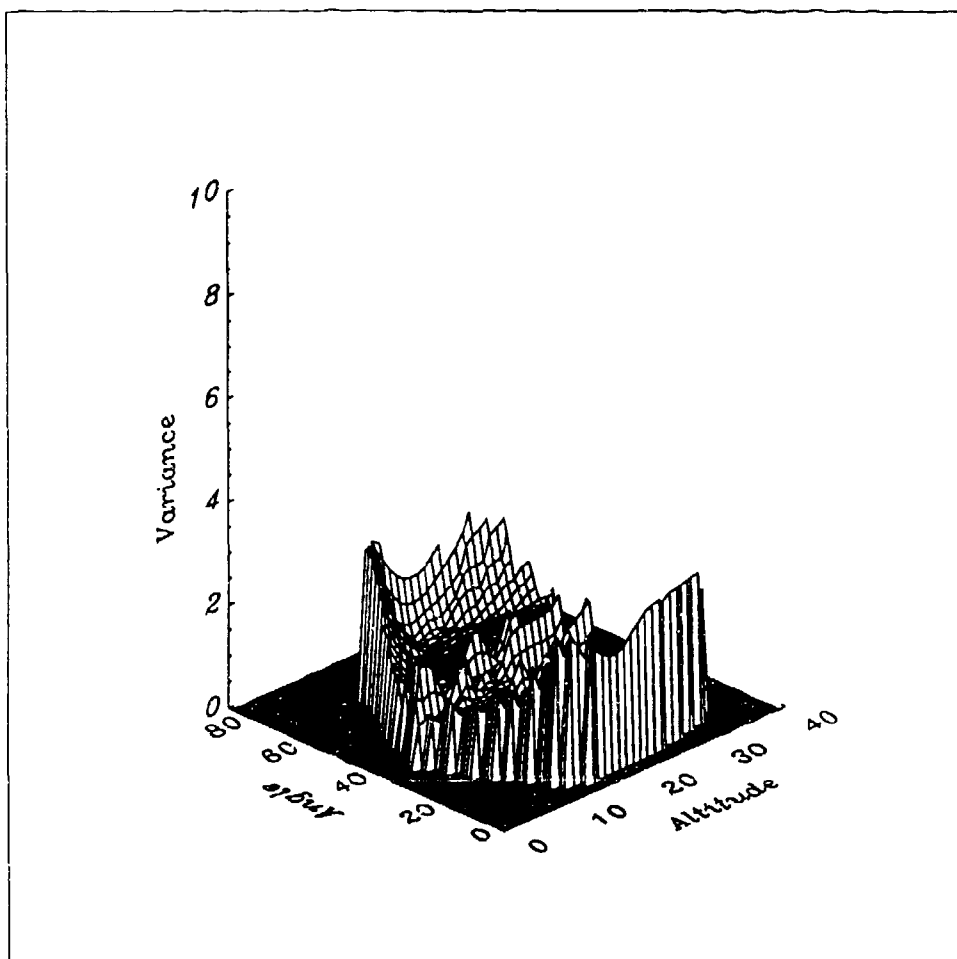
Estimation Variances for Subject 133



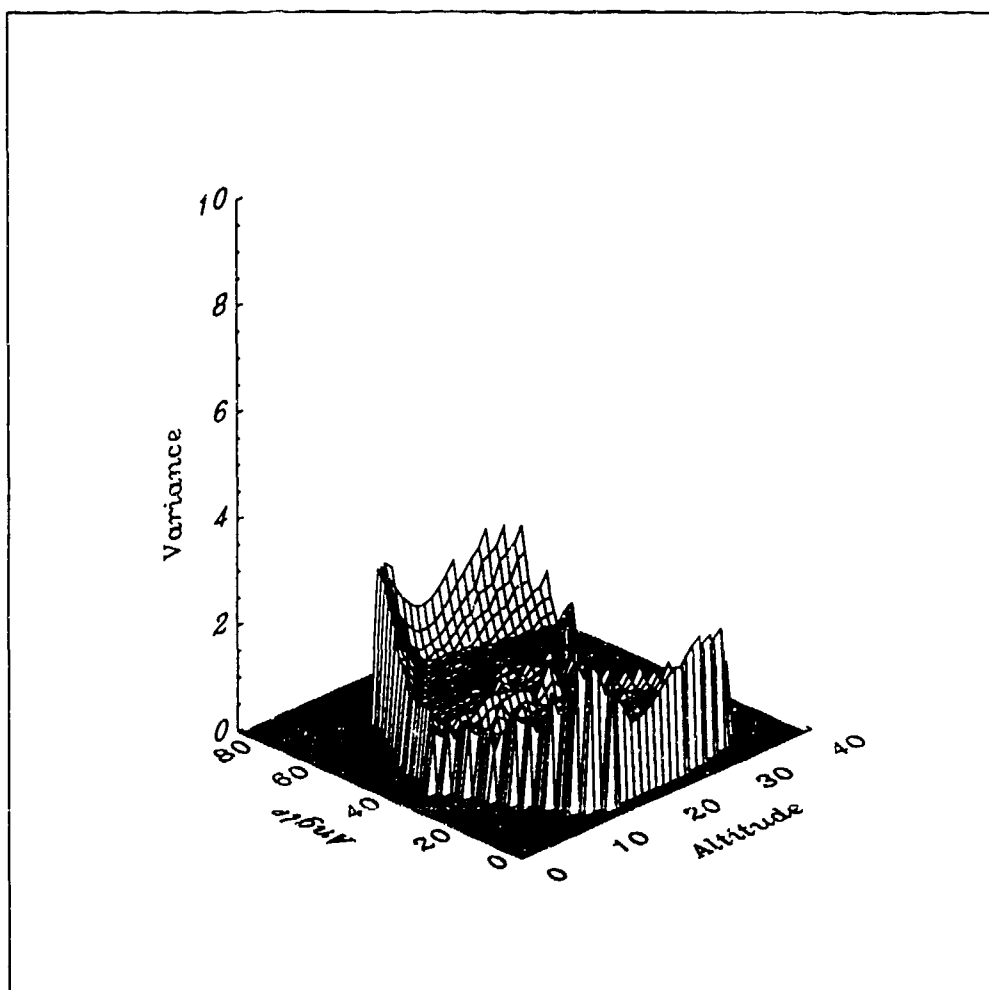
Estimation Variances for Subject 136



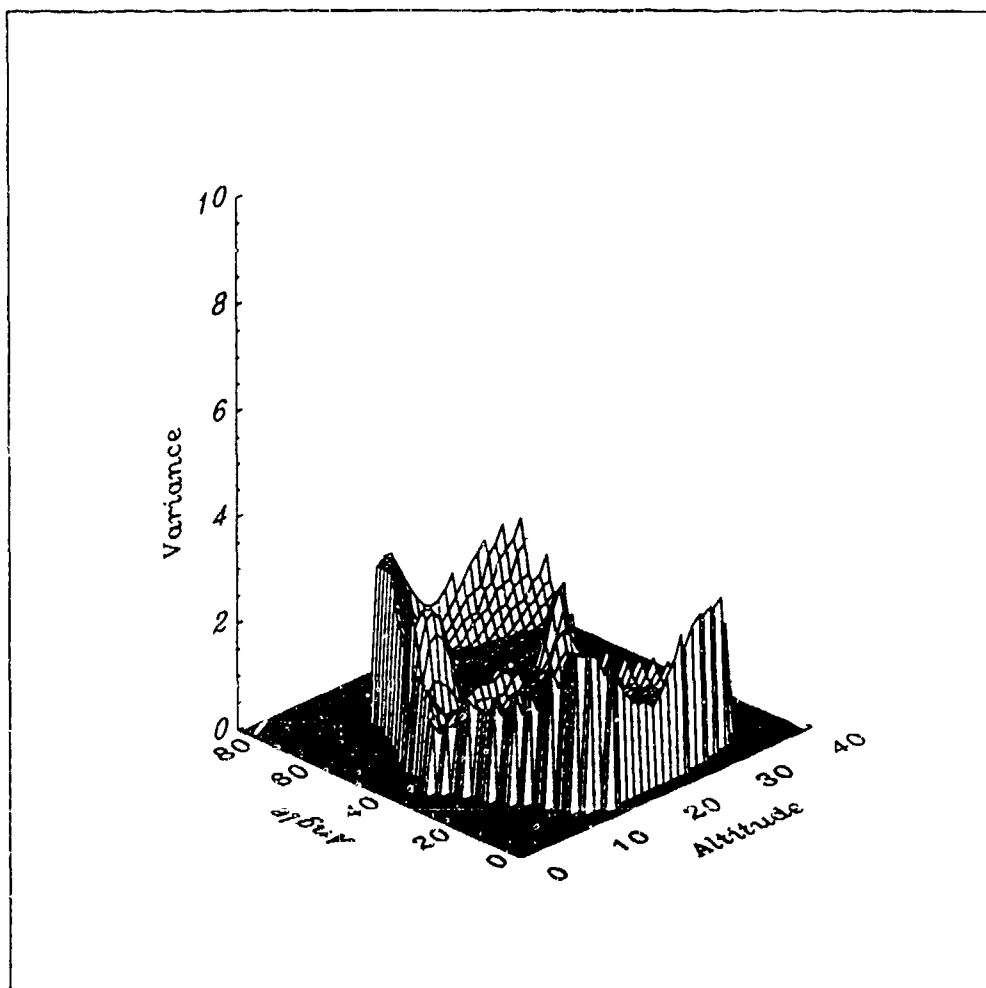
Estimation Variances for Subject 140



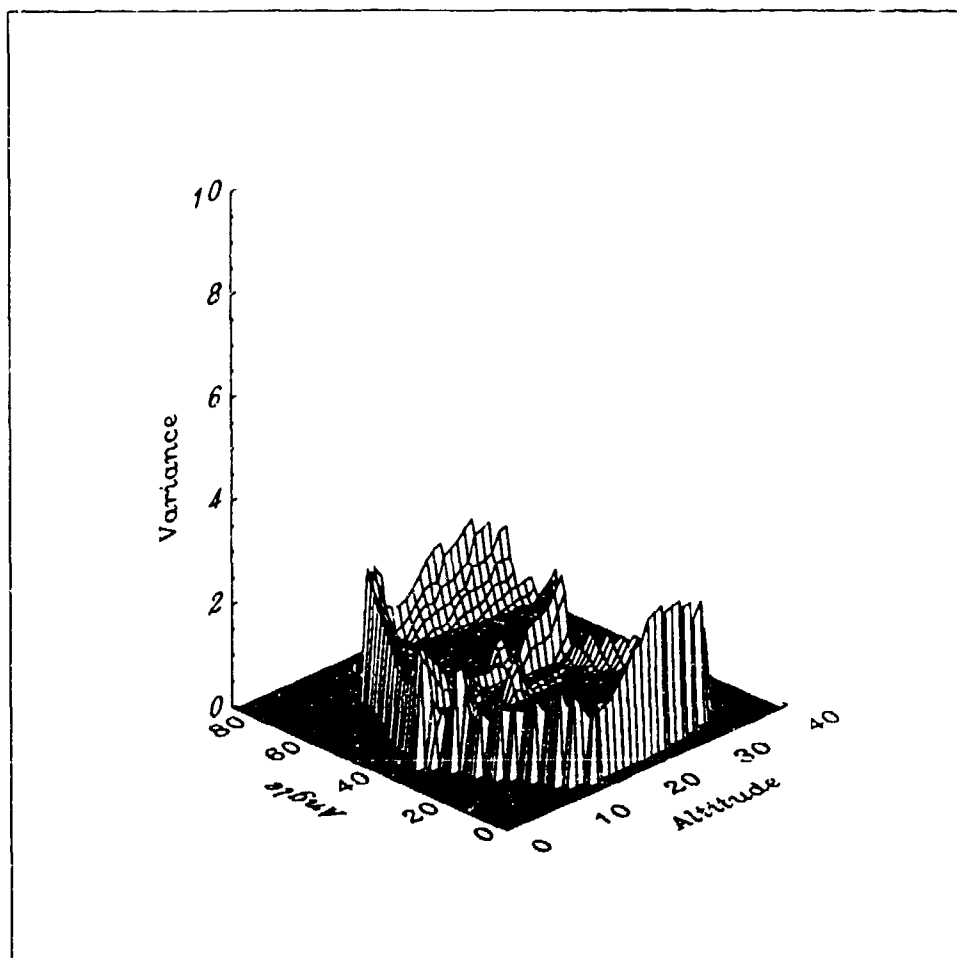
Estimation Variances for Subject 142



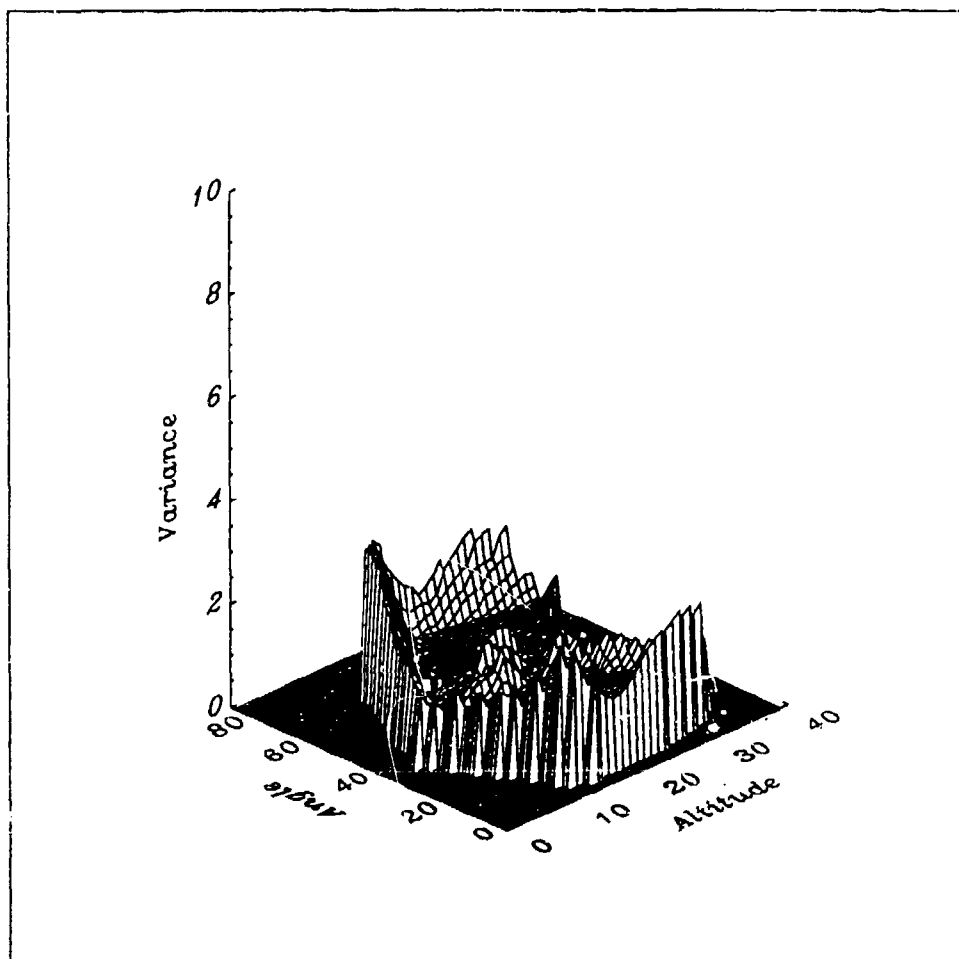
Estimation Variances for Subject 153



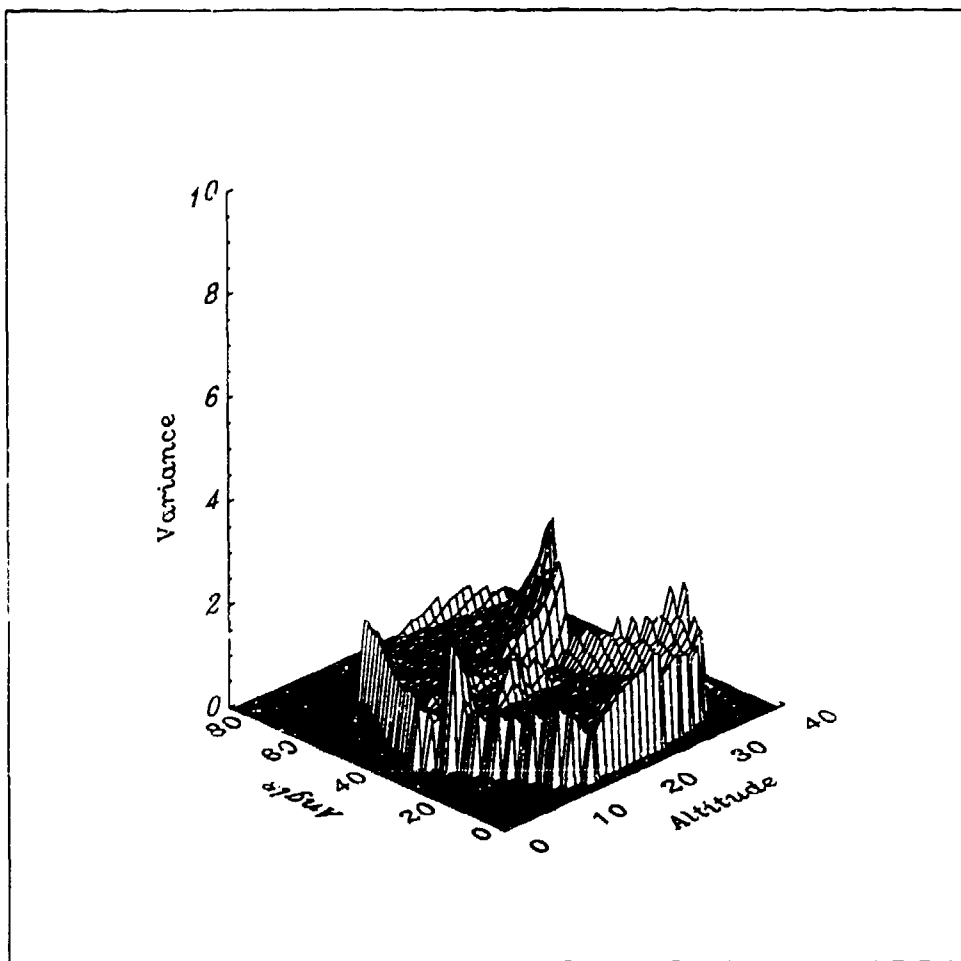
Estimation Variances for Subject 154



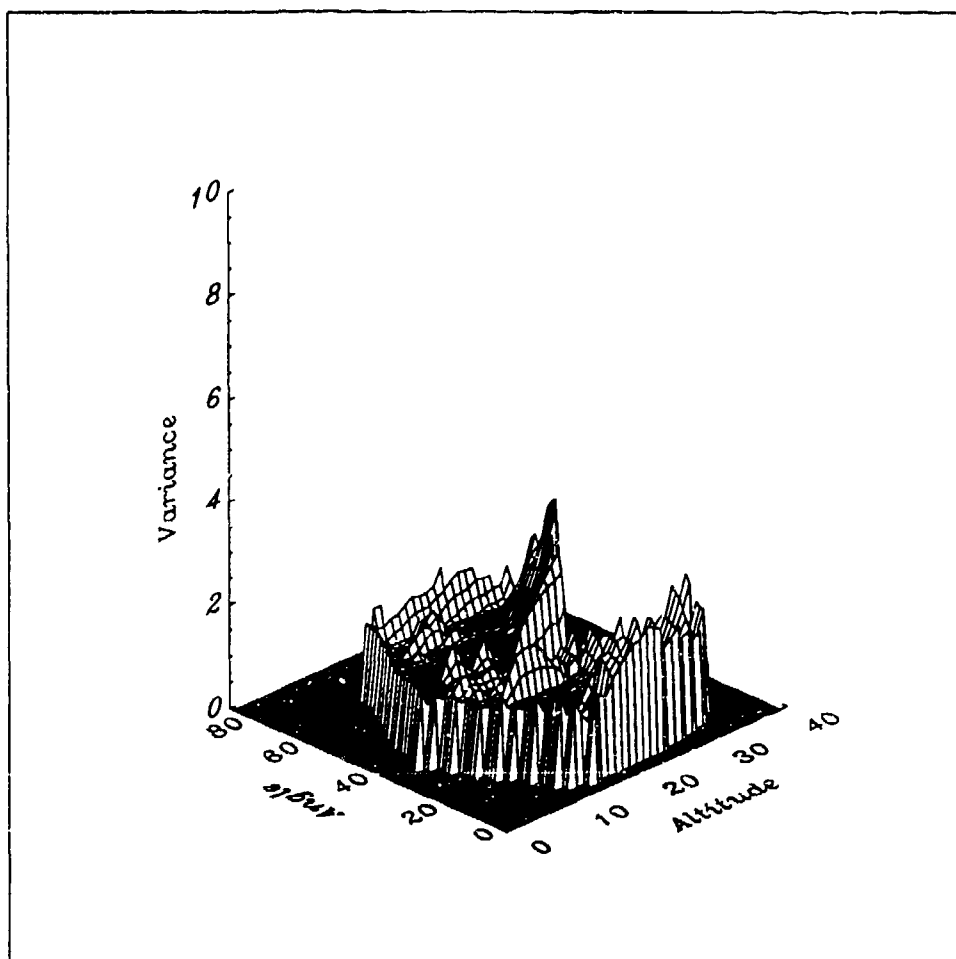
Estimation Variances for Subject 155



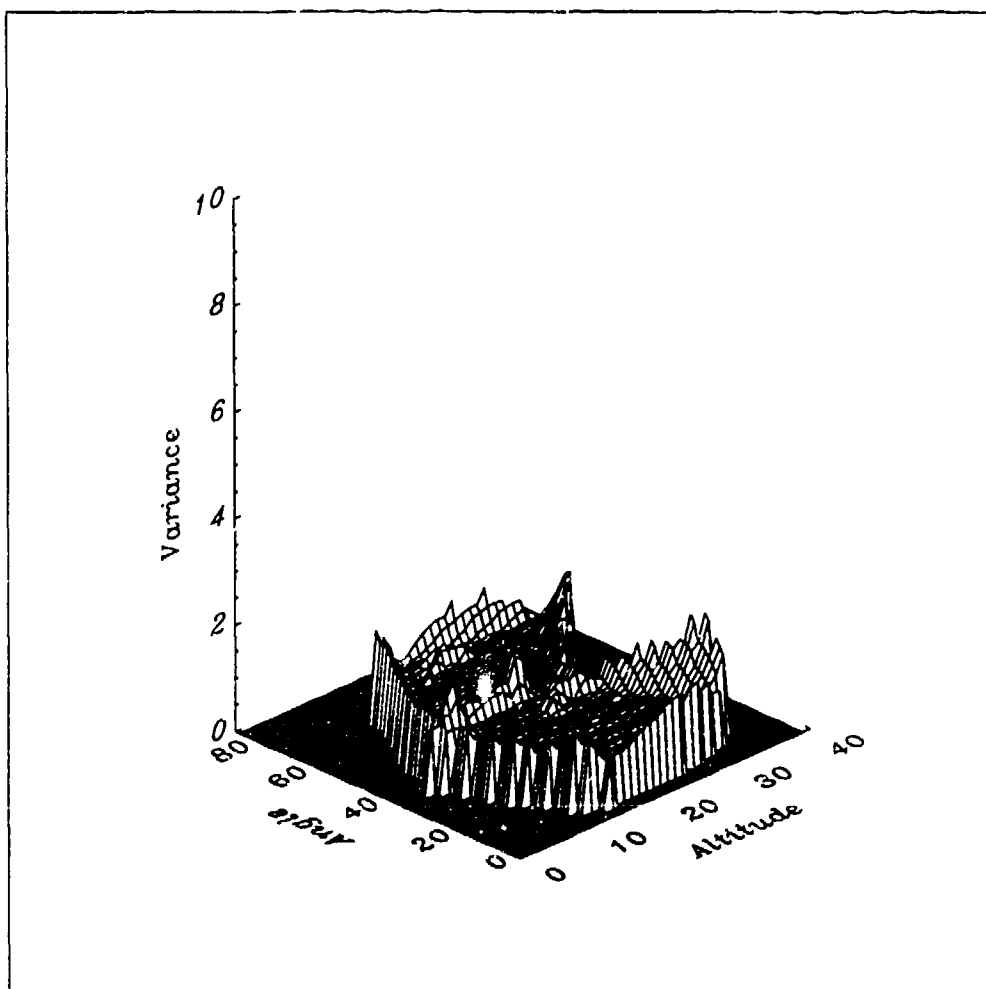
Estimation Variances for Subject 159



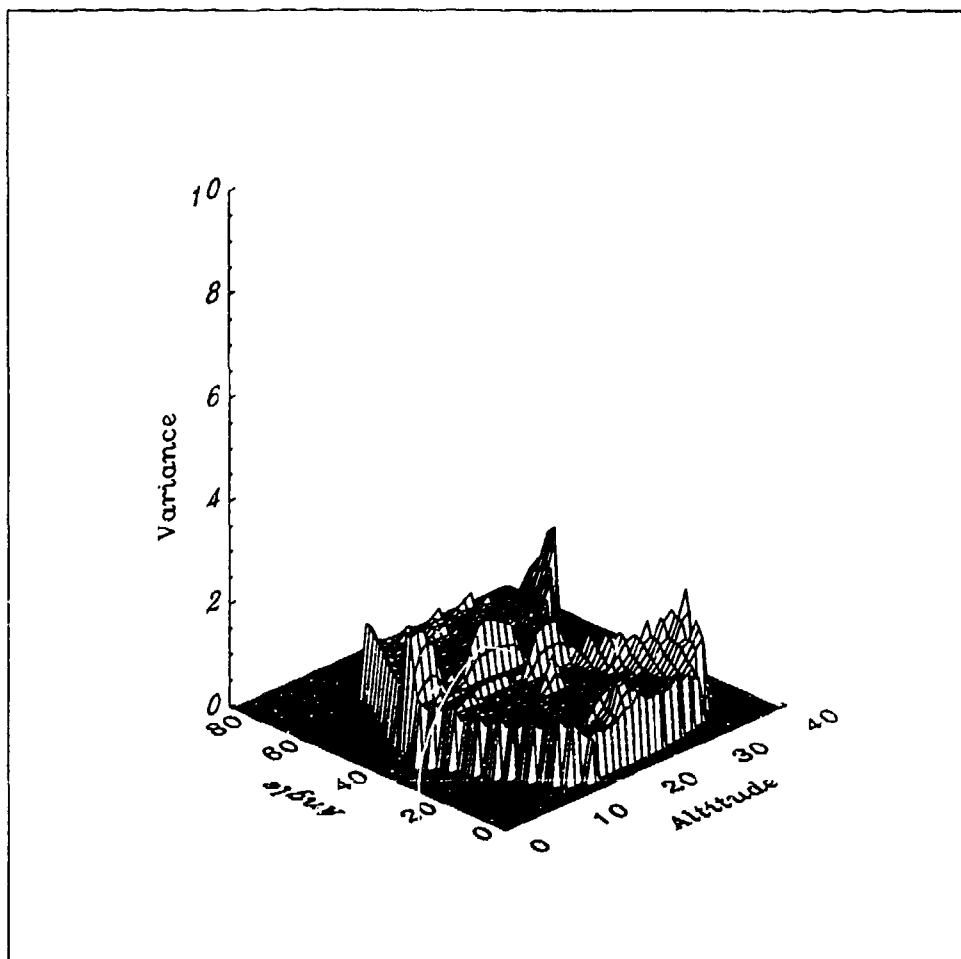
Estimation Variances for Subject 160



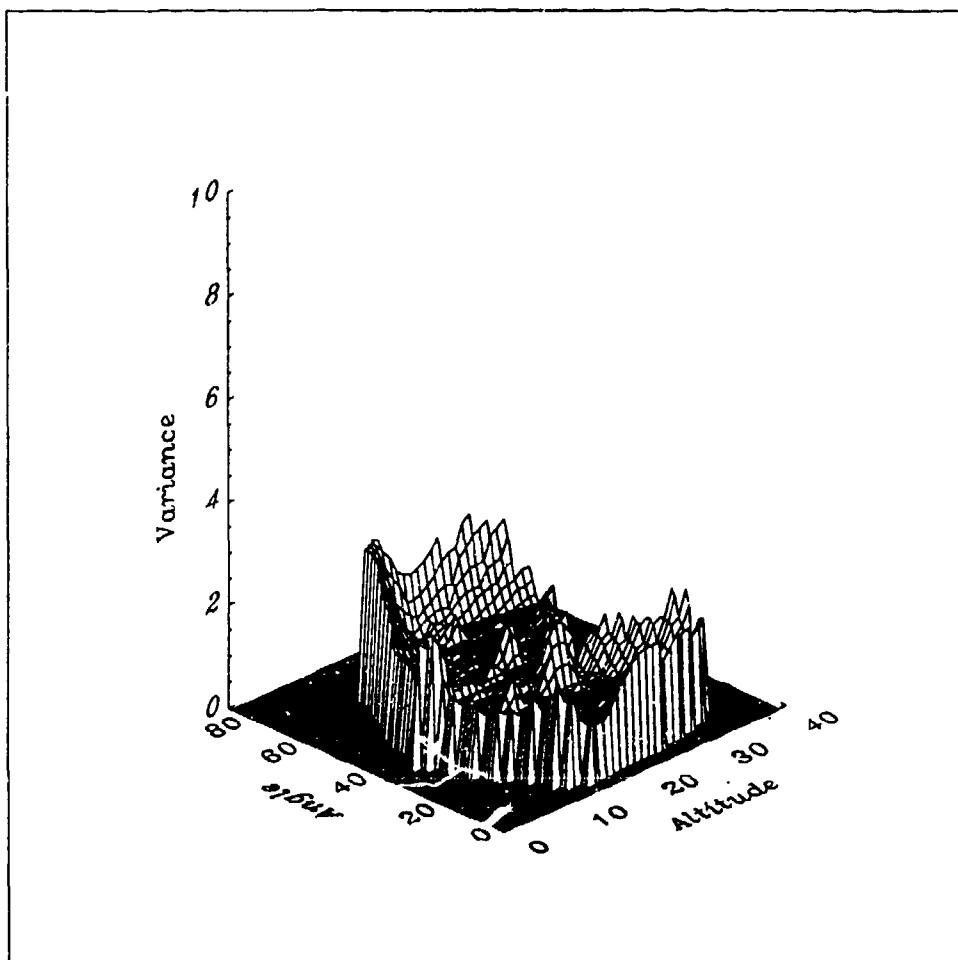
Estimation Variances for Subject 161



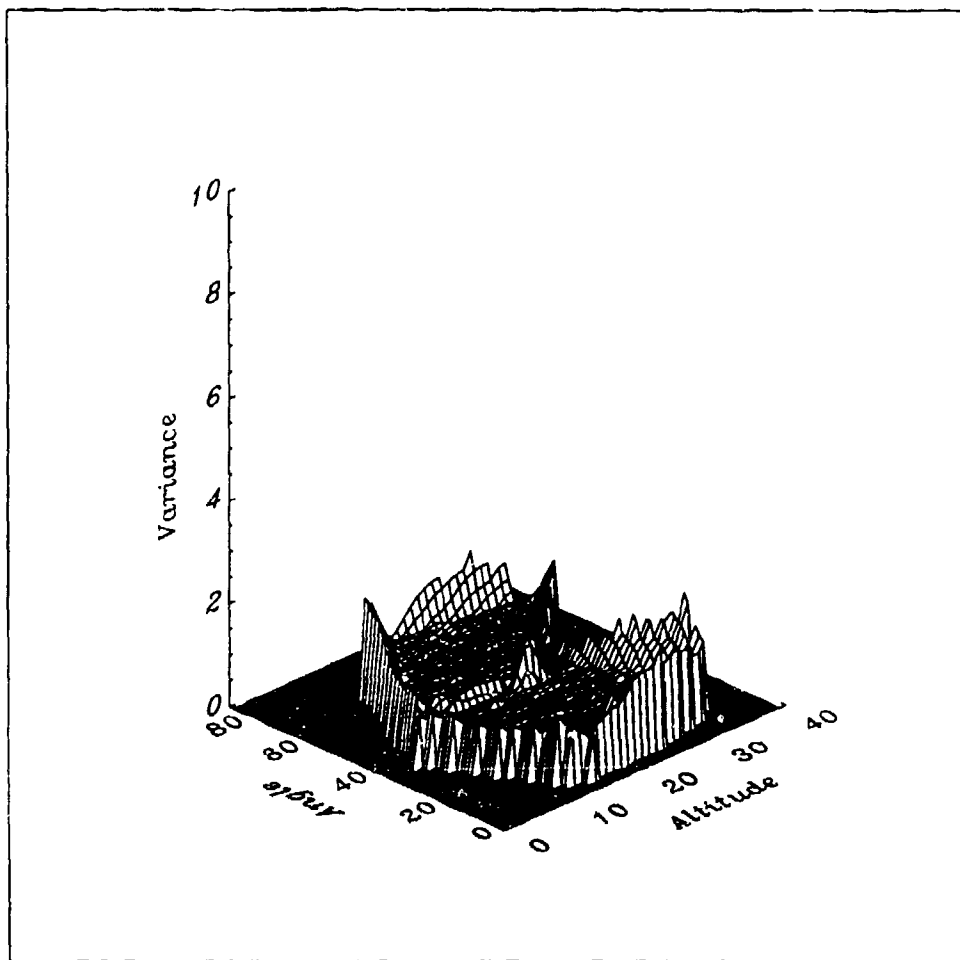
Estimation Variances for Subject 167



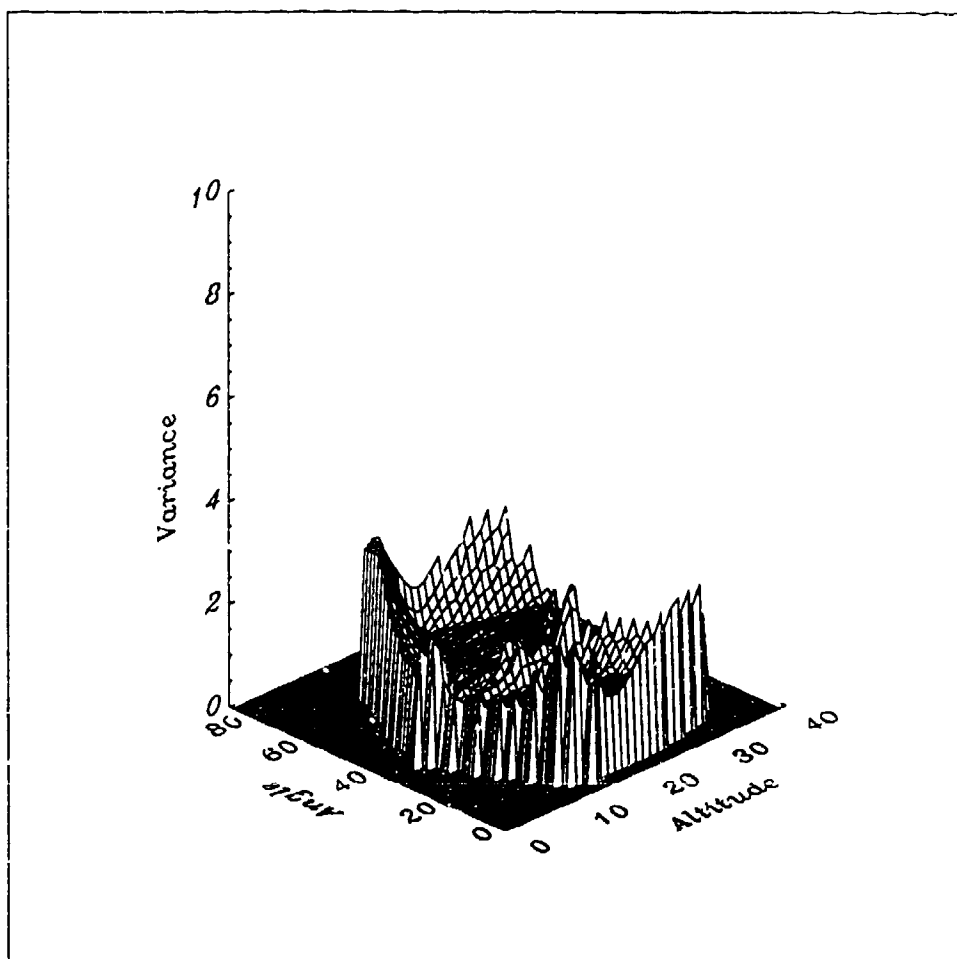
Estimation Variances for Subject 171



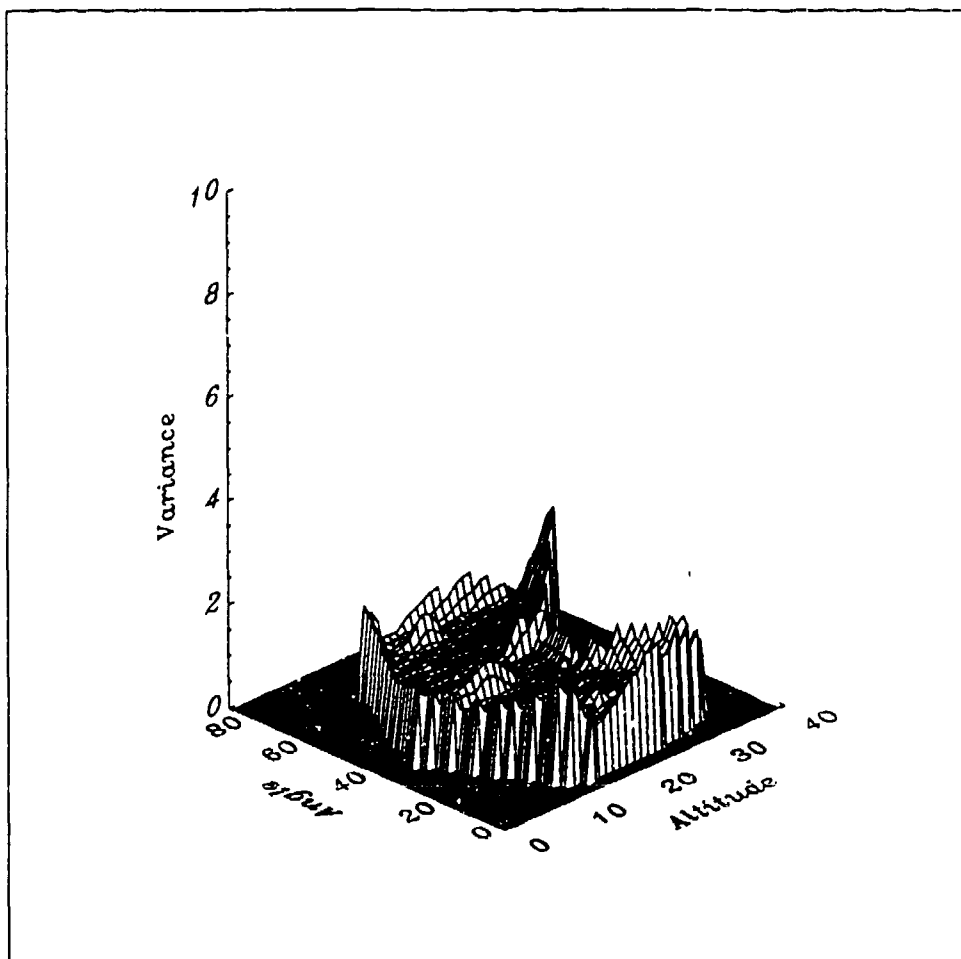
Estimation Variances for Subject 173



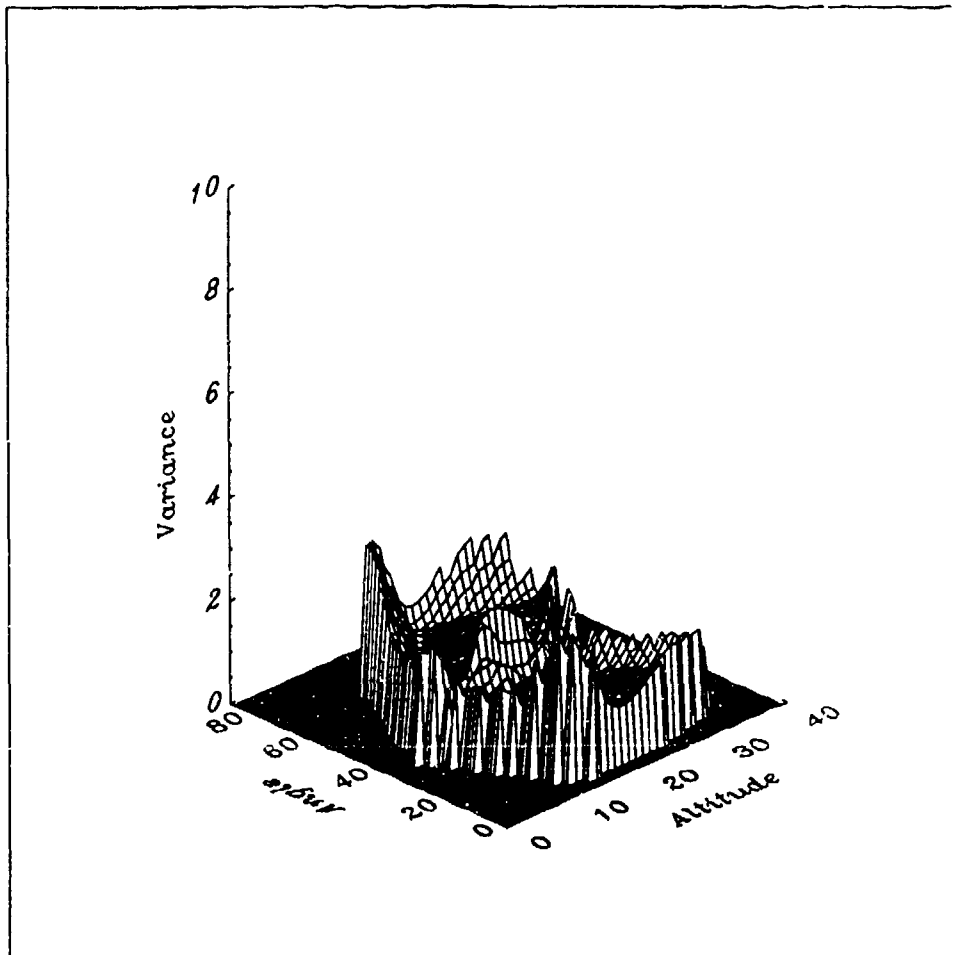
Estimation Variances for Subject 176



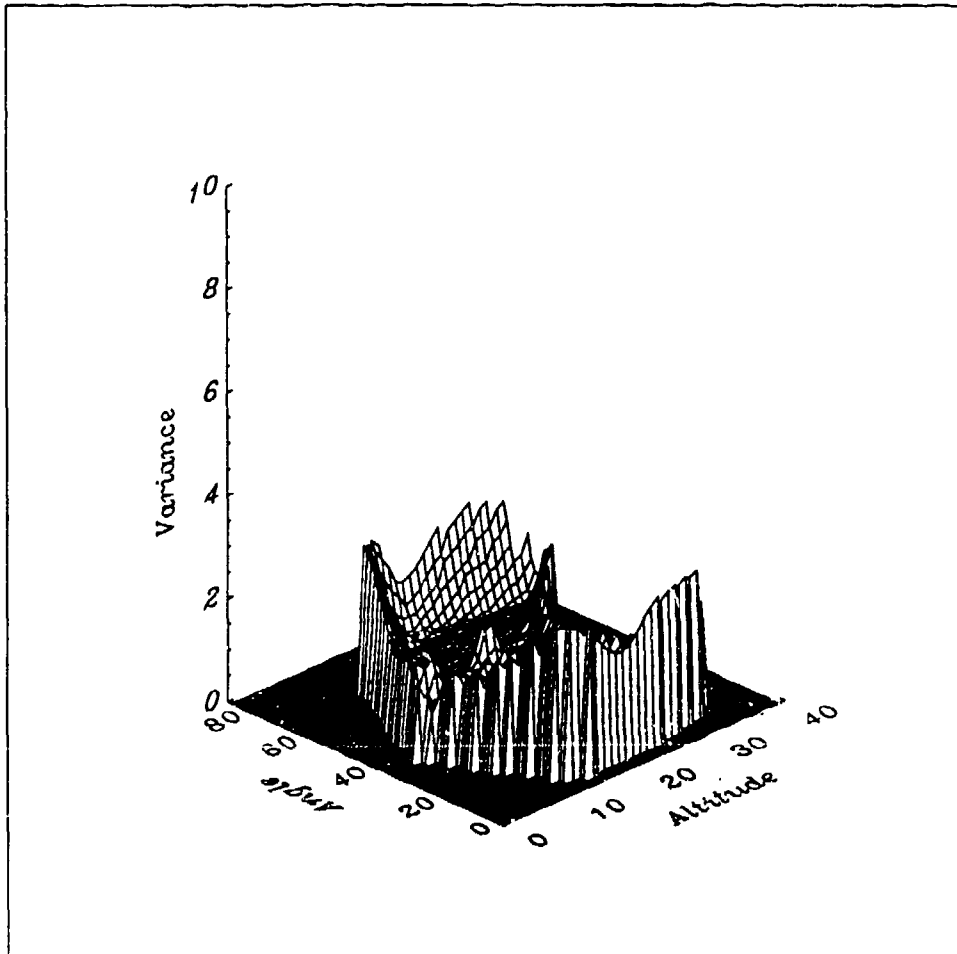
Estimation Variances for Subject 183



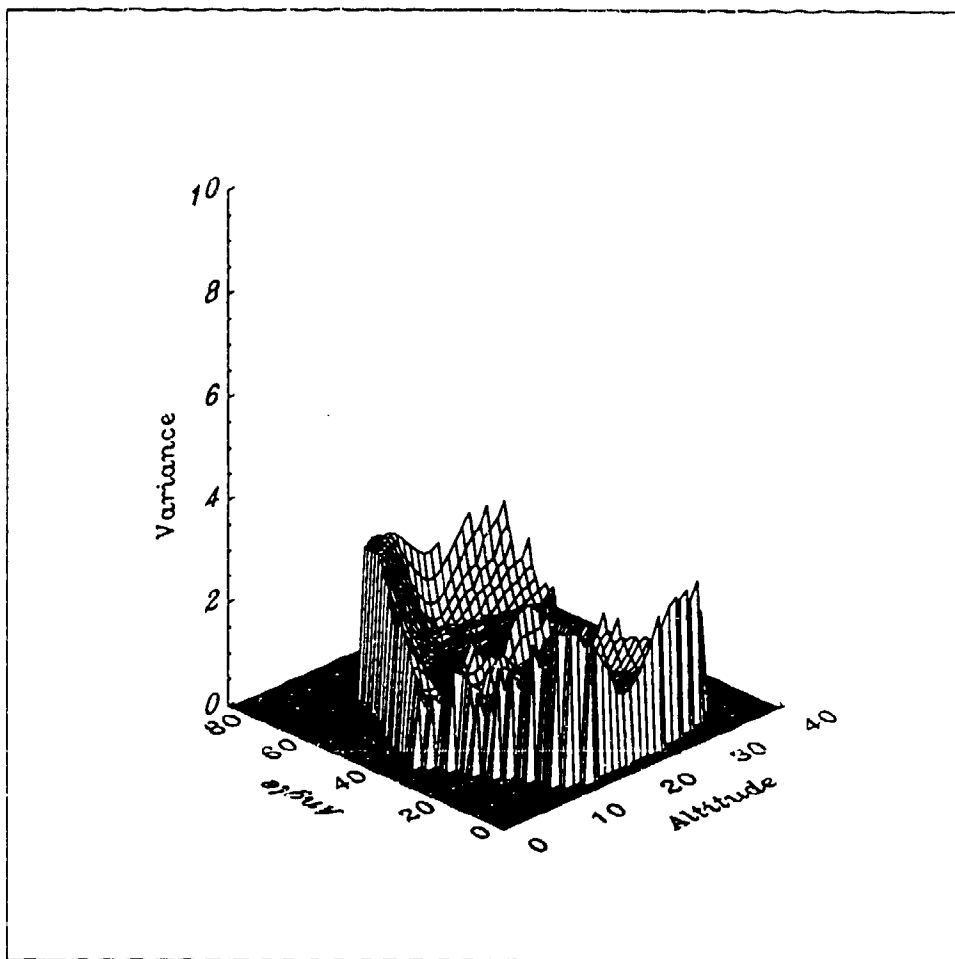
Estimation Variances for Subject 185



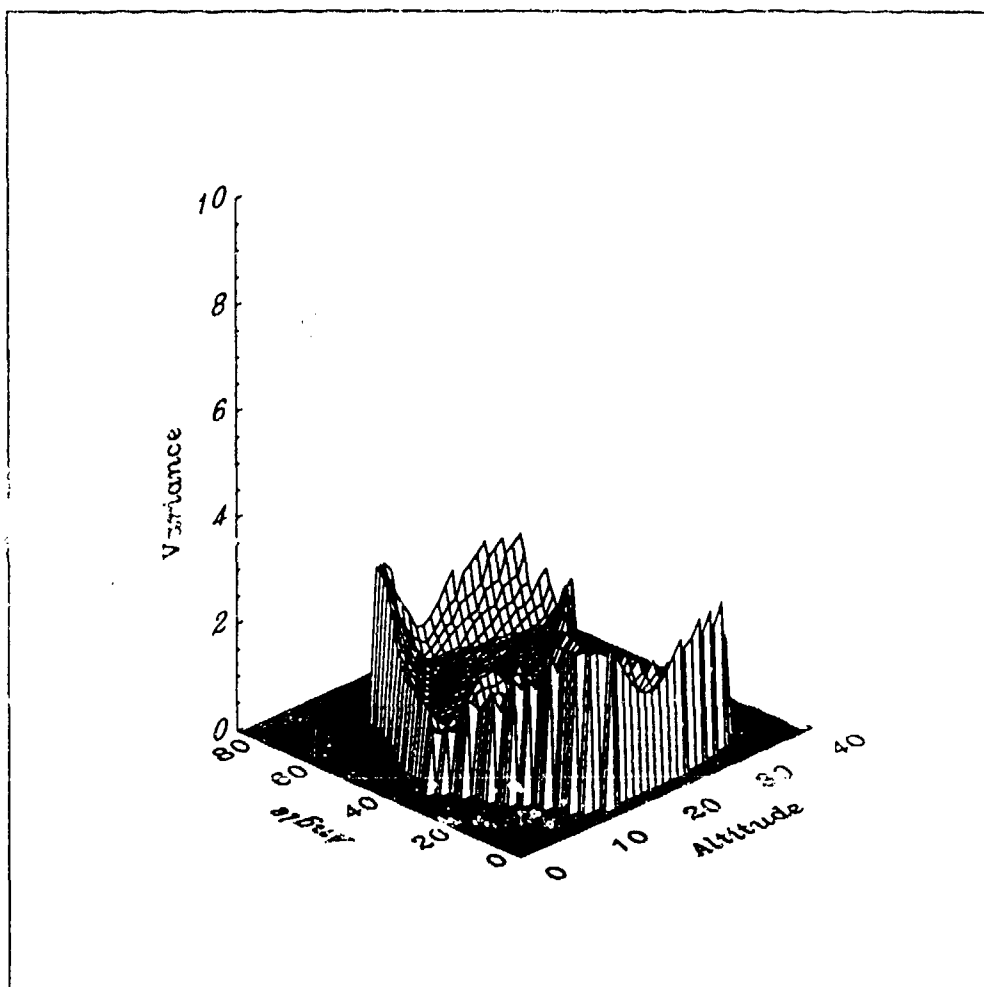
Estimation Variances for Subject 112



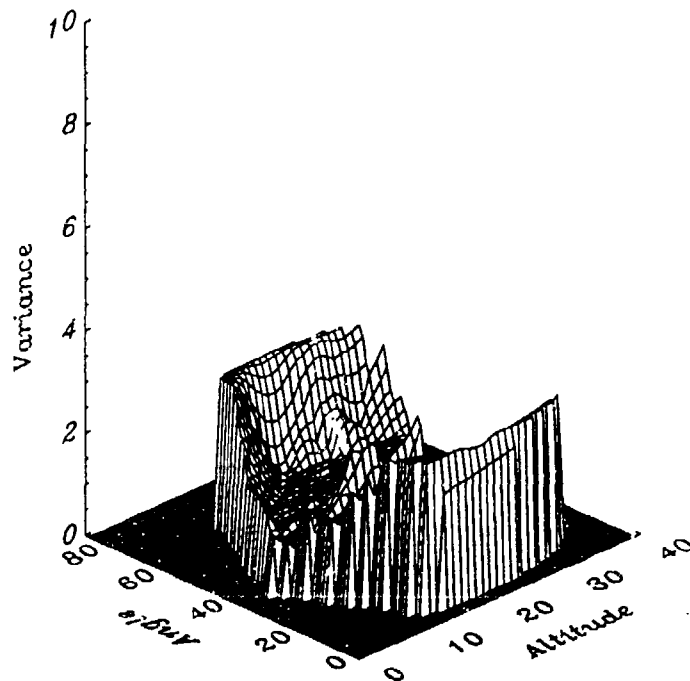
Estimation Variances for Subject 141



Estimation Variances for Subject 152



Estimation Variances for Subject 156



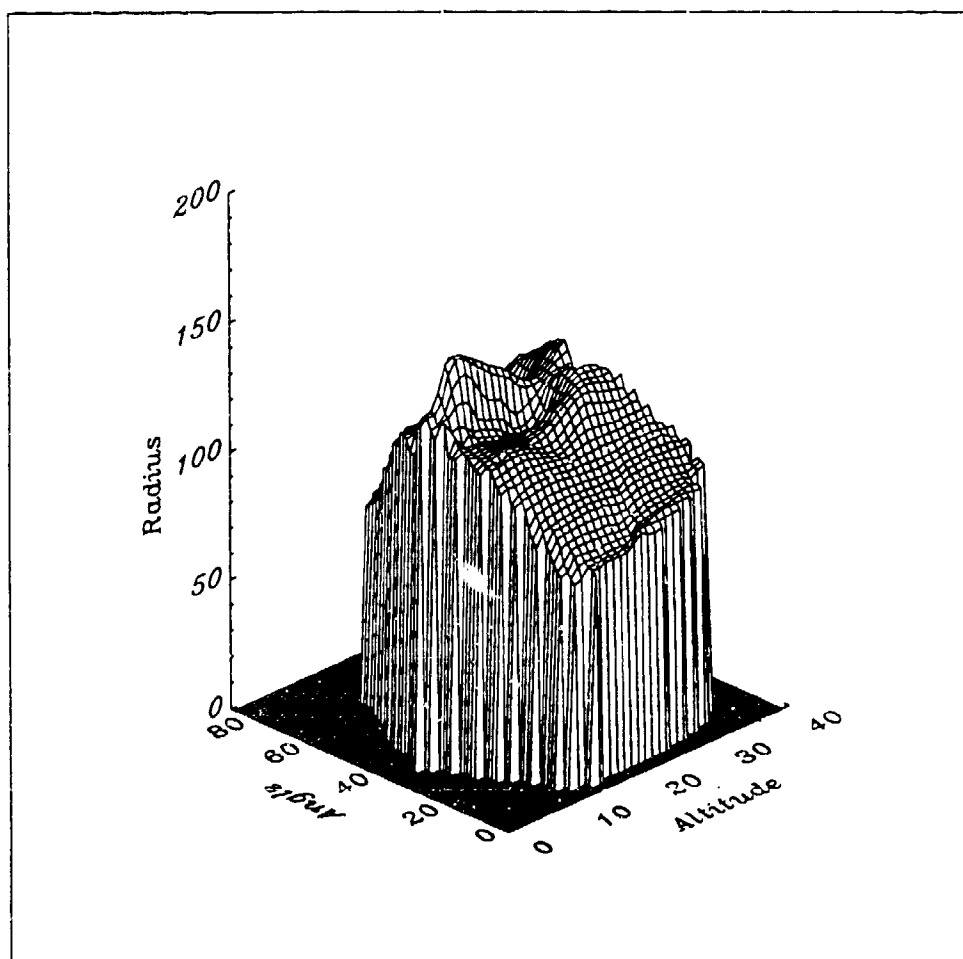
Estimation Variances for Subject 199

## Appendix E. *Updated Surface Plots*

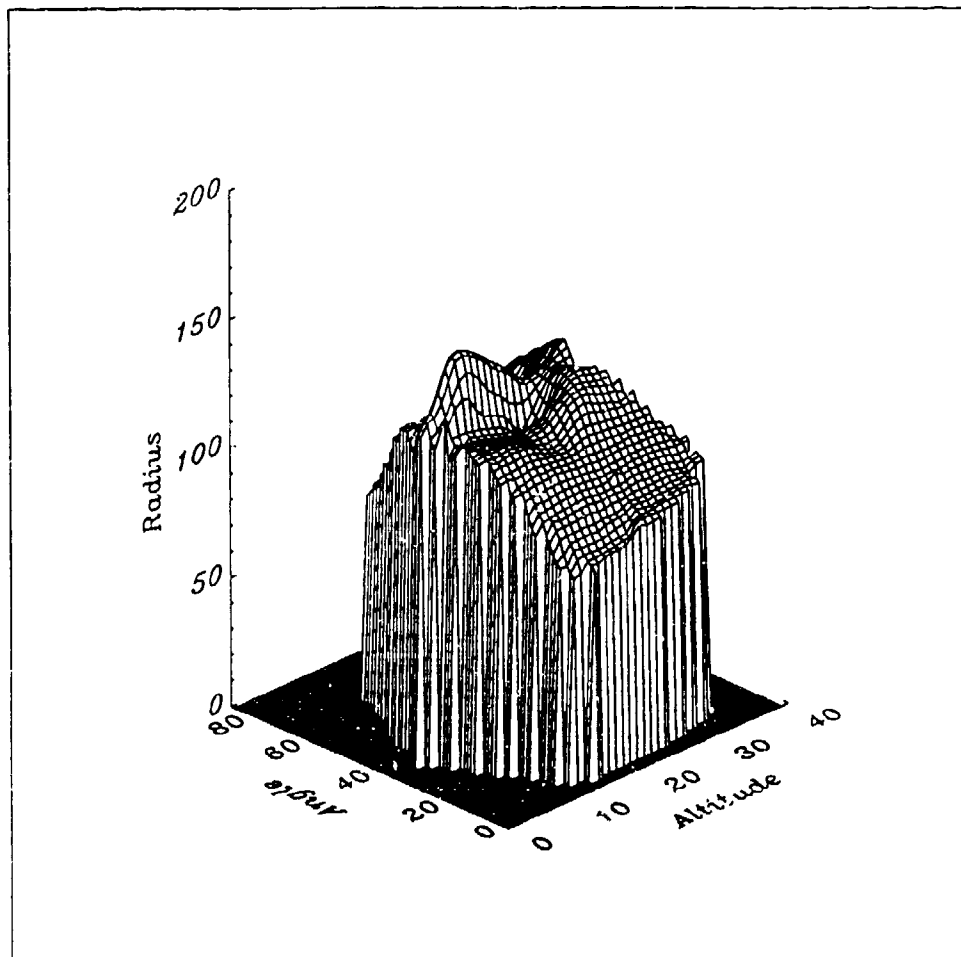
This appendix includes the updated surfaces and variances obtained by the updating procedure. The surfaces were produced sequentially beginning with the lowest numbered subject. Each surface represents the aggregate surface of all the subjects up to and including the most recent update.

### *Updated Facial Surfaces*

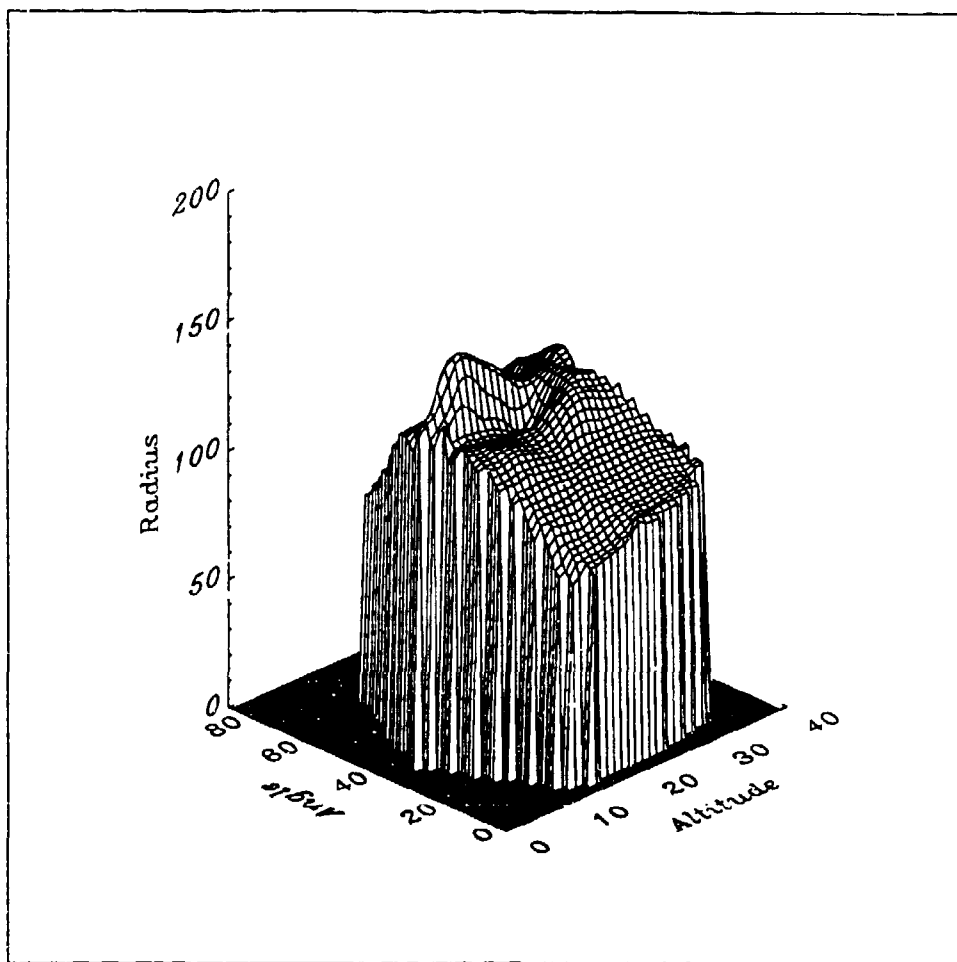
This section includes the surface estimates.



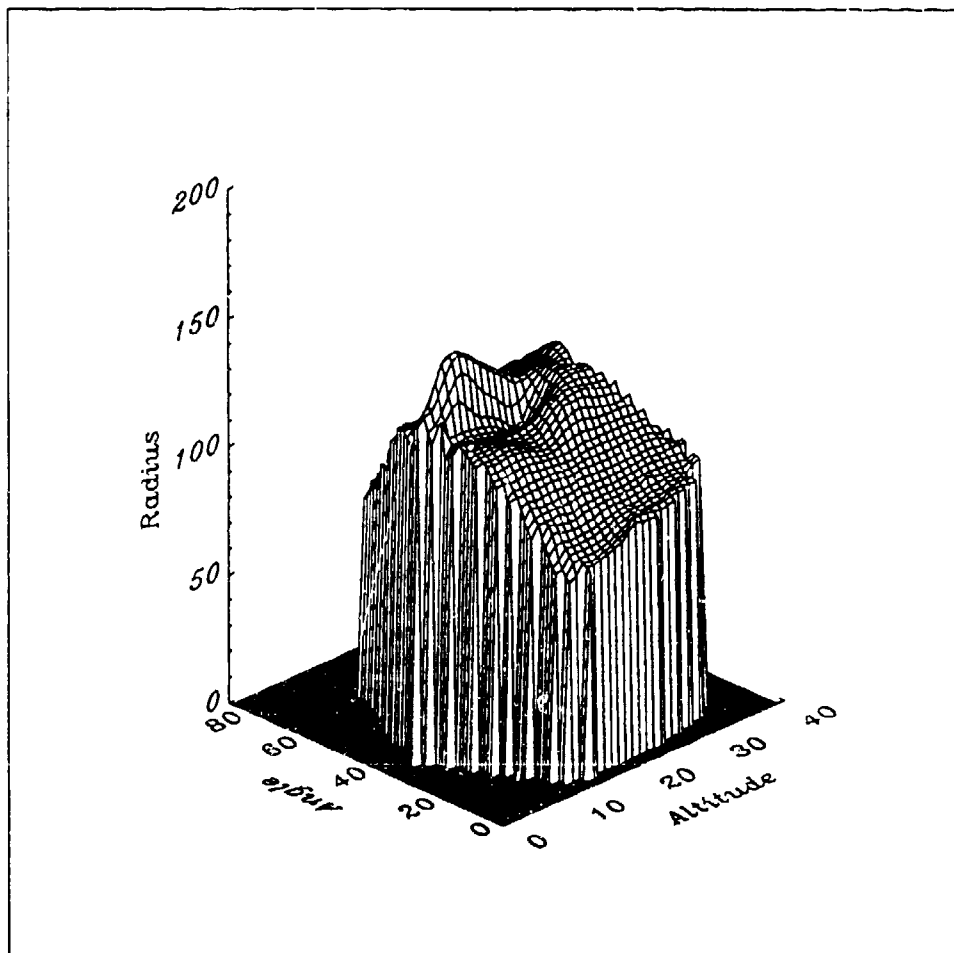
Updated Surface After Subject 09



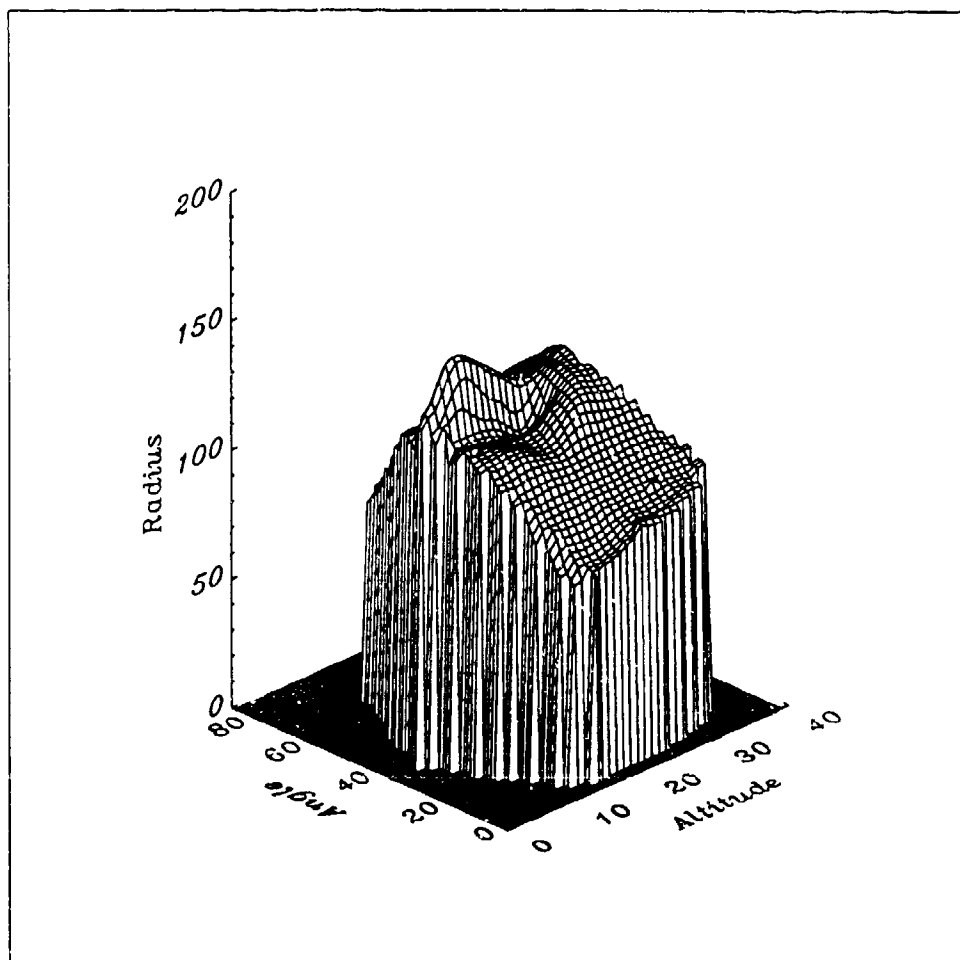
Updated Surface After Subject 10



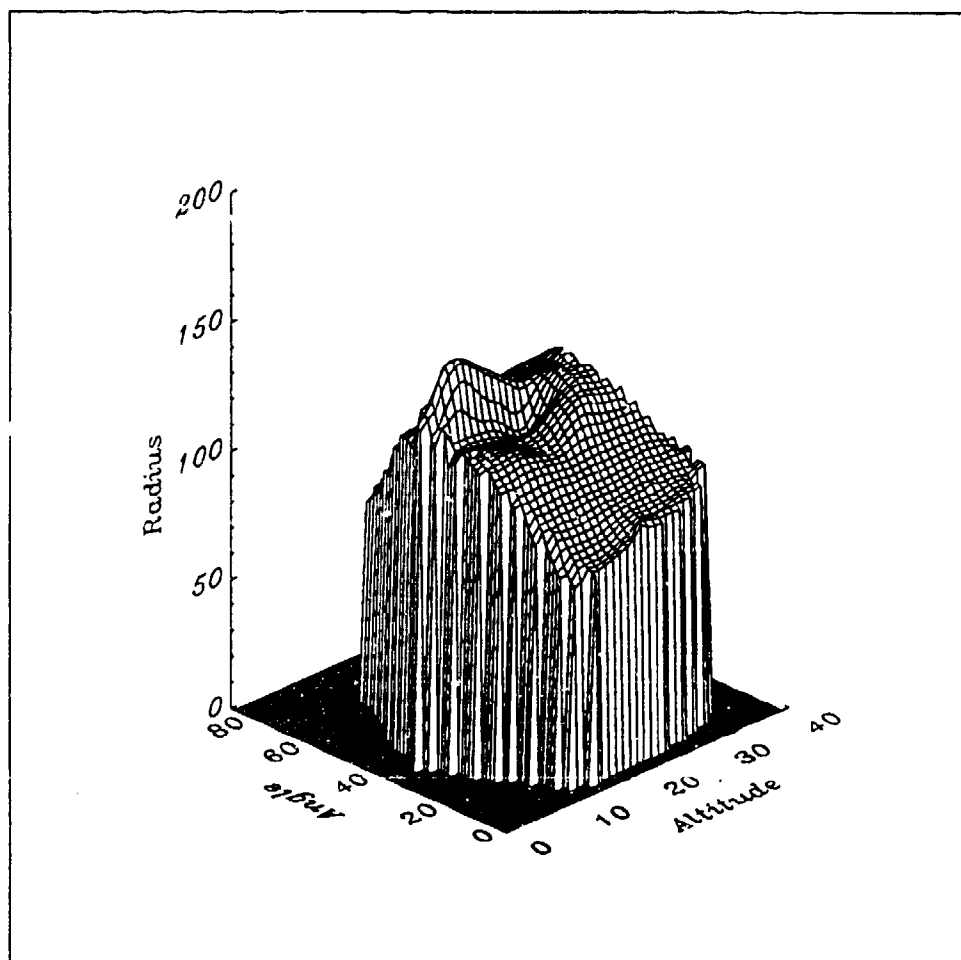
Updated Surface After Subject 60



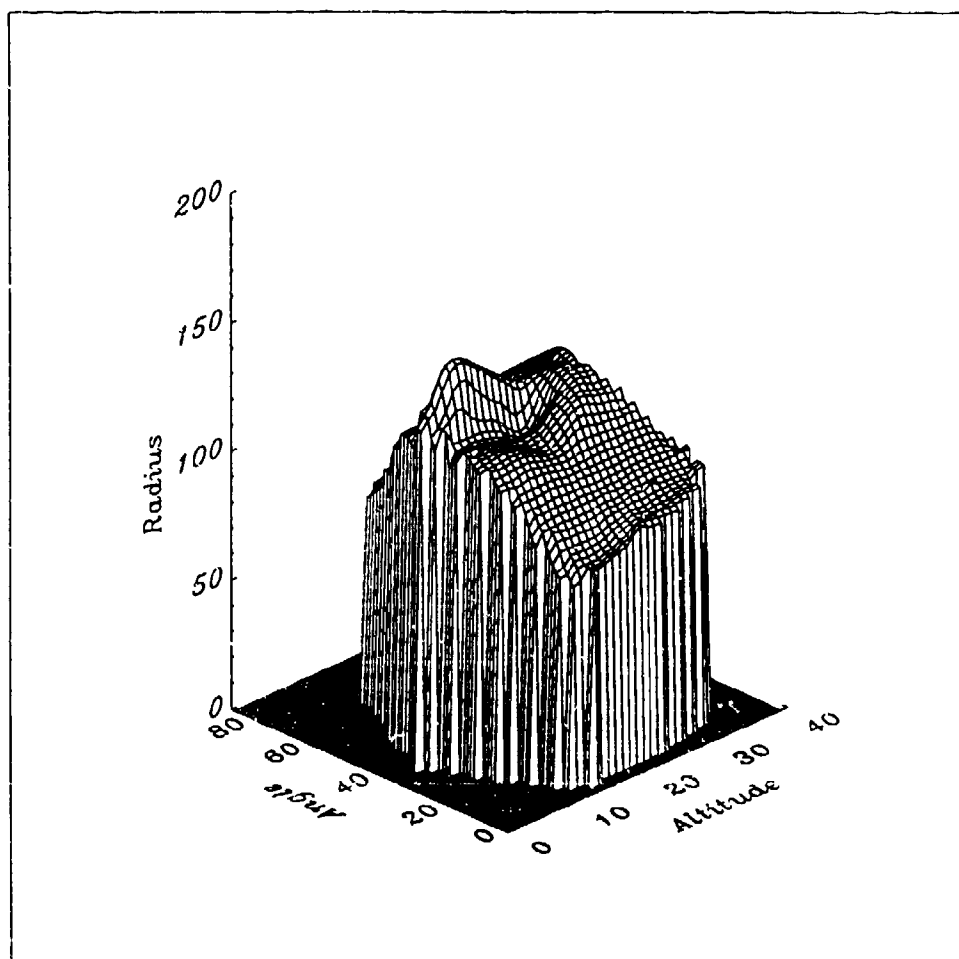
Updated Surface After Subject 68



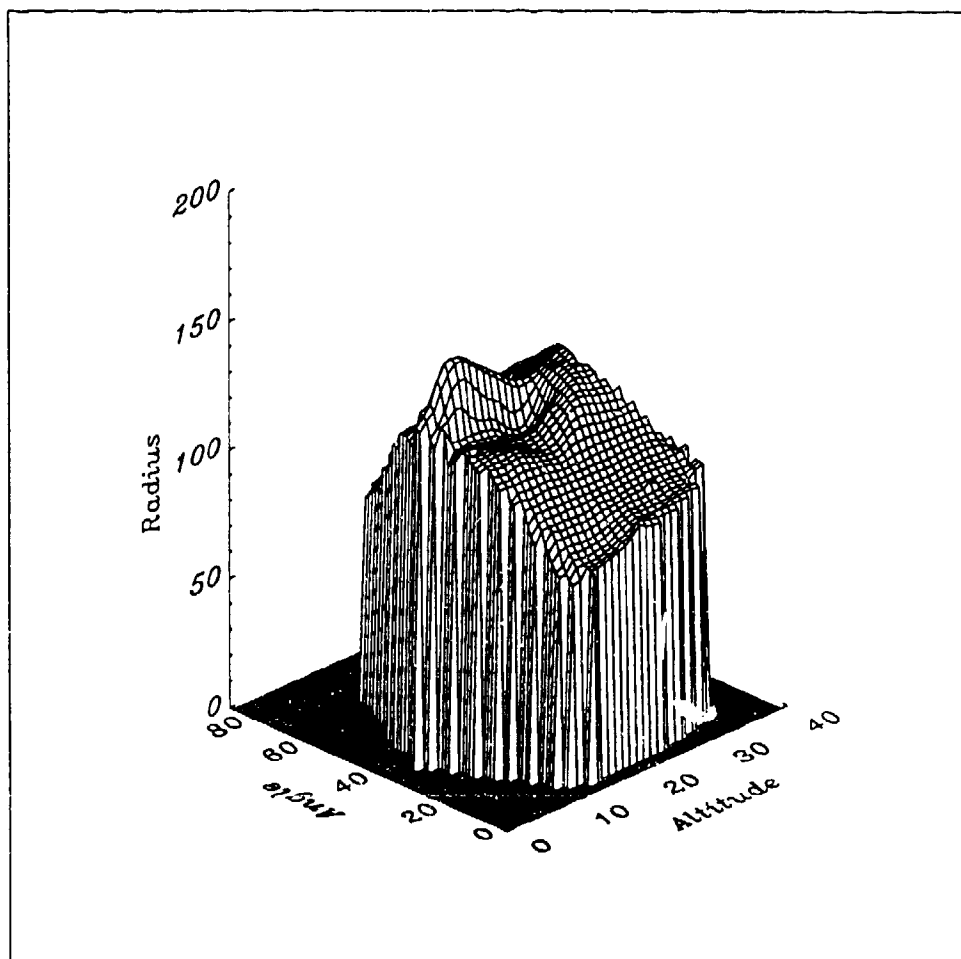
Updated Surface After Subject 114



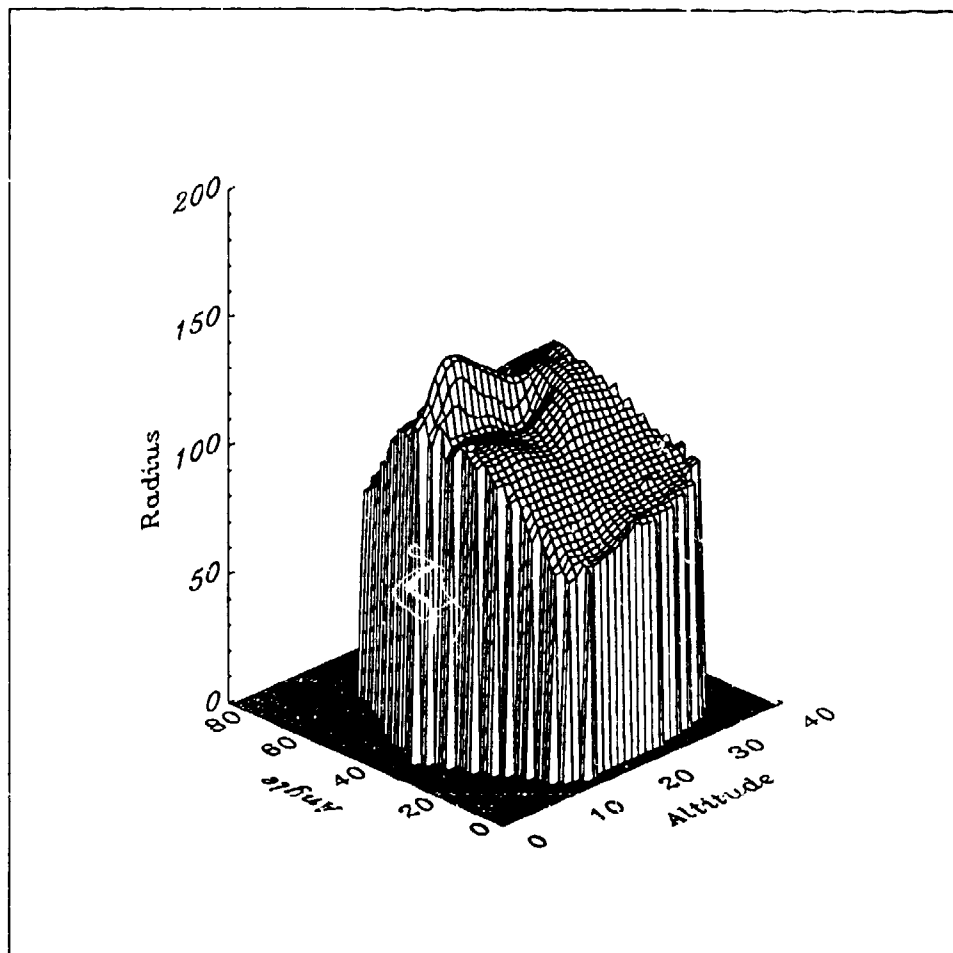
Updated Surface After Subject 116



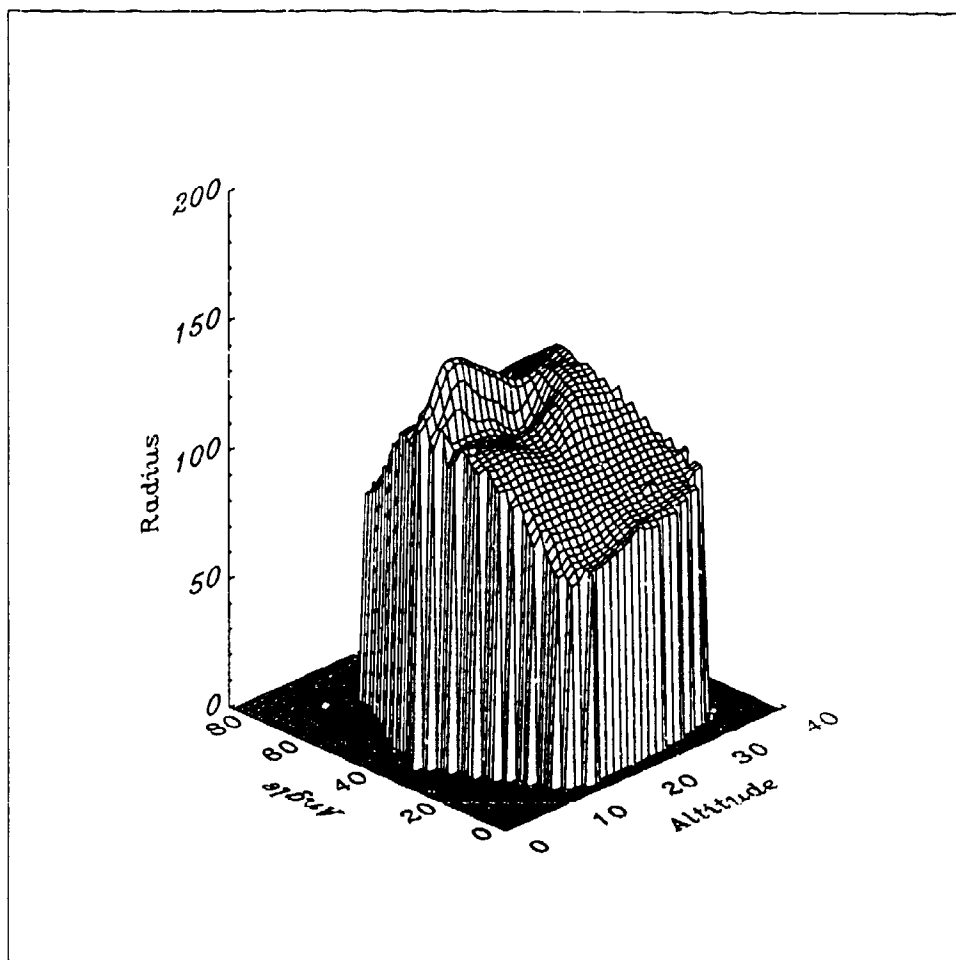
Updated Surface After Subject 118



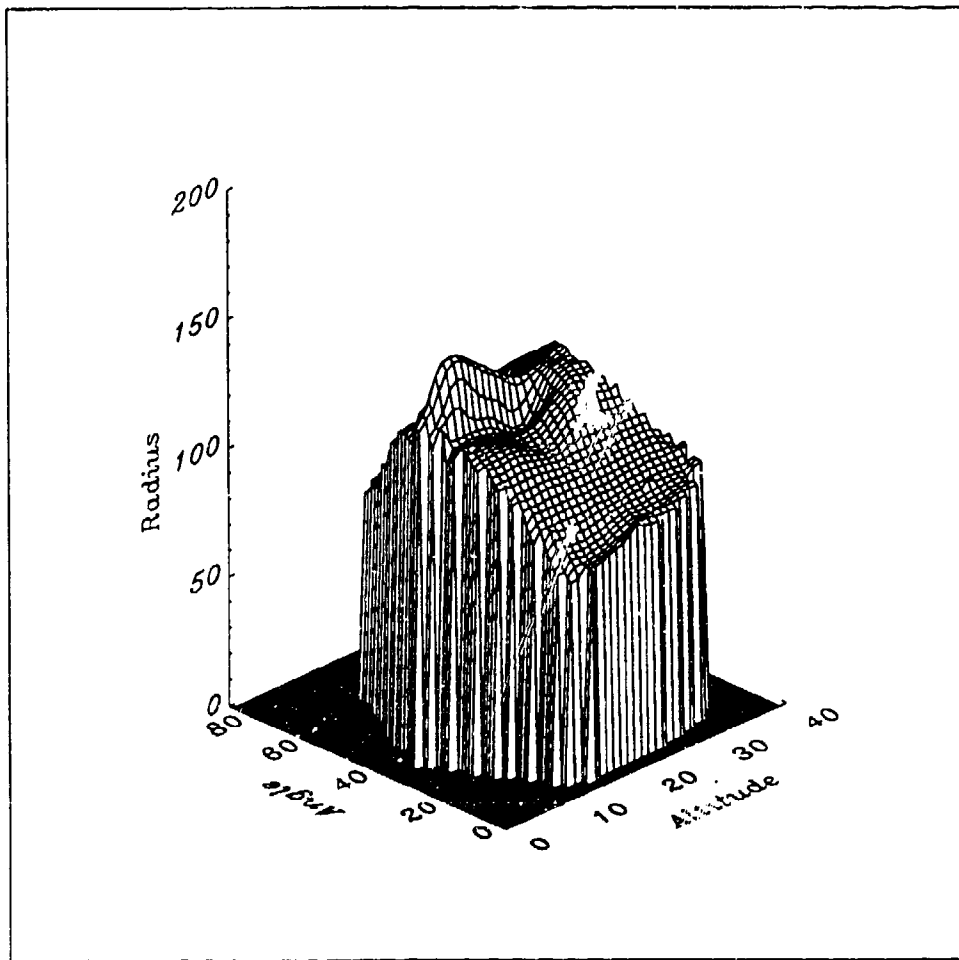
Updated Surface After Subject 122



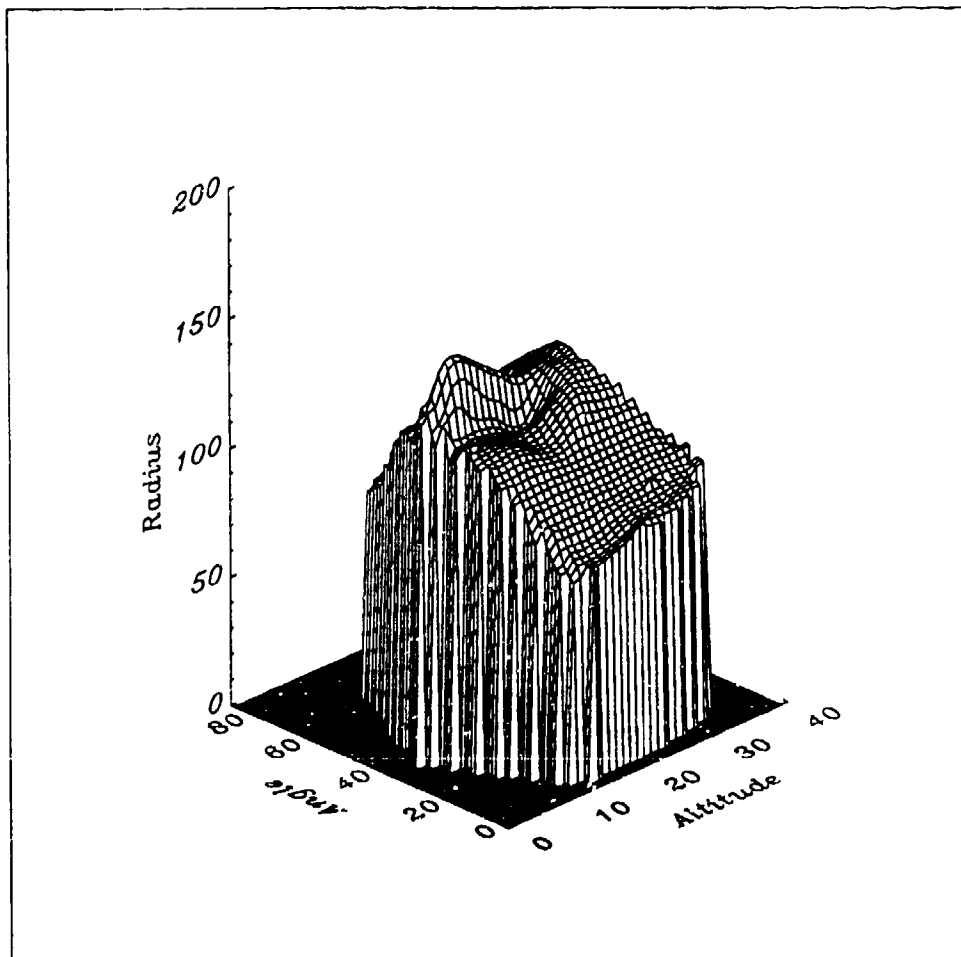
Updated Surface After Subject 130



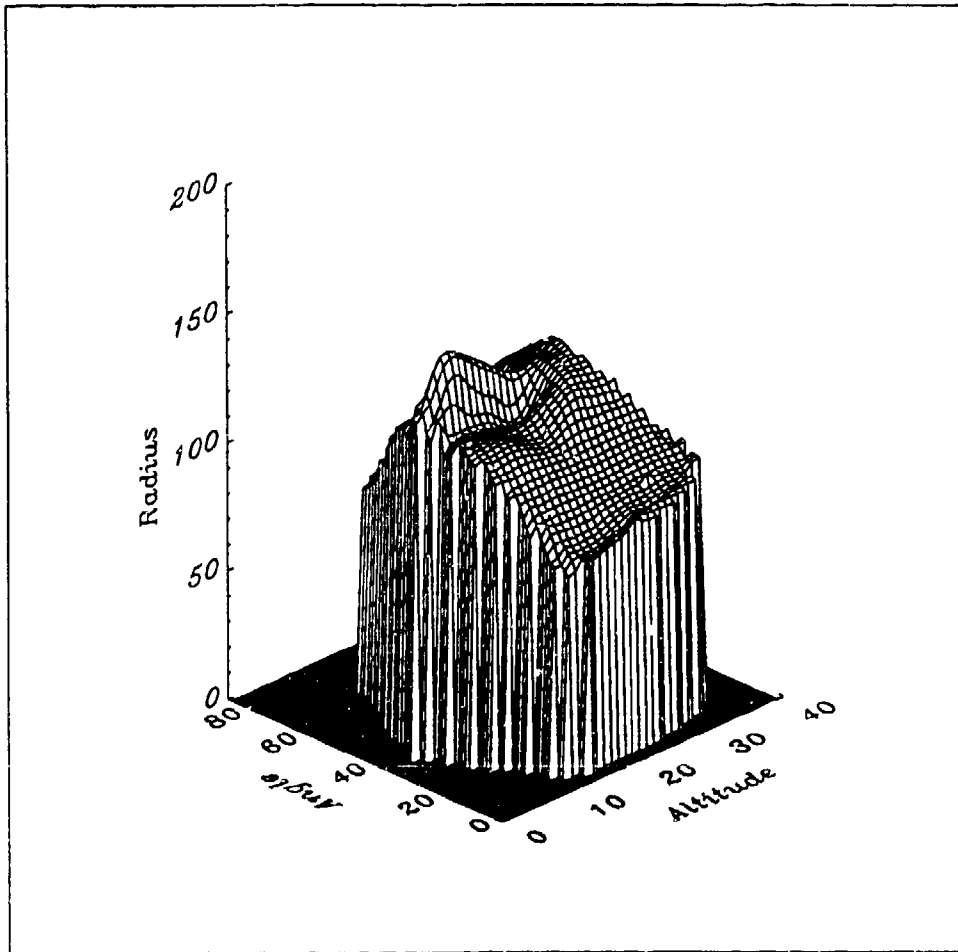
Updated Surface After Subject 133



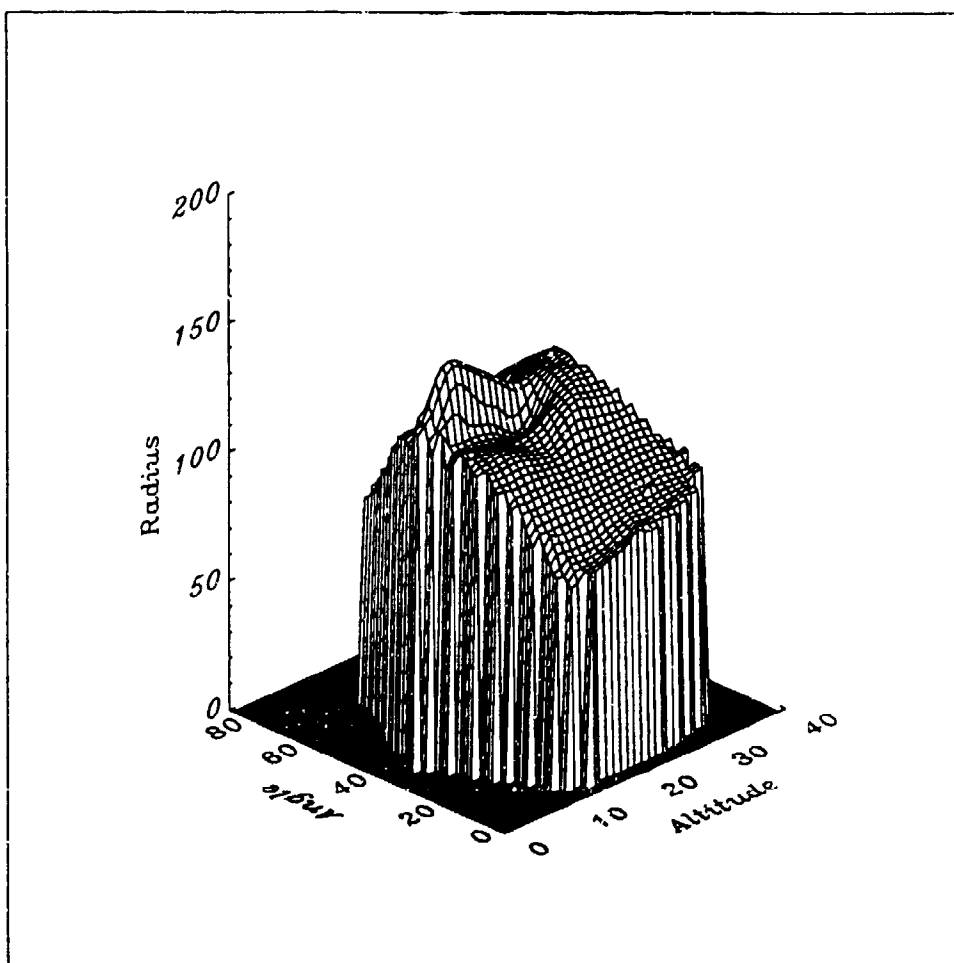
Updated Surface After Subject 136



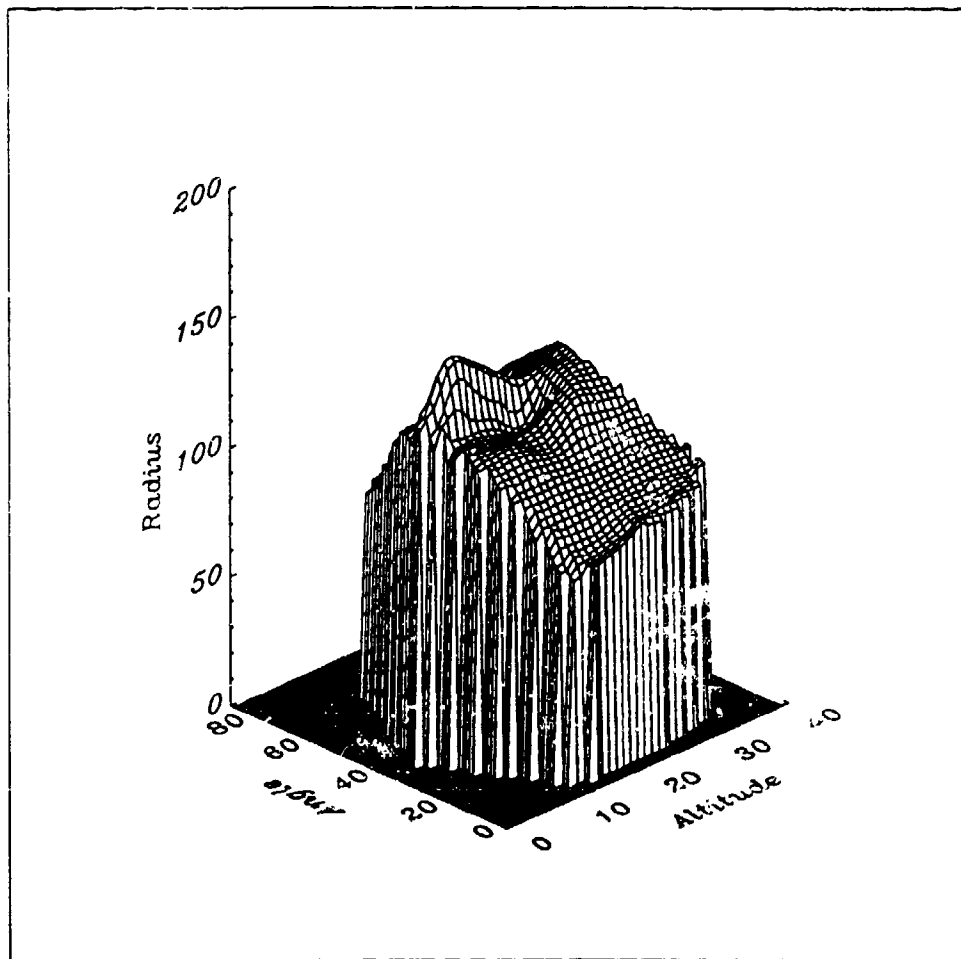
Updated Surface After Subject 140



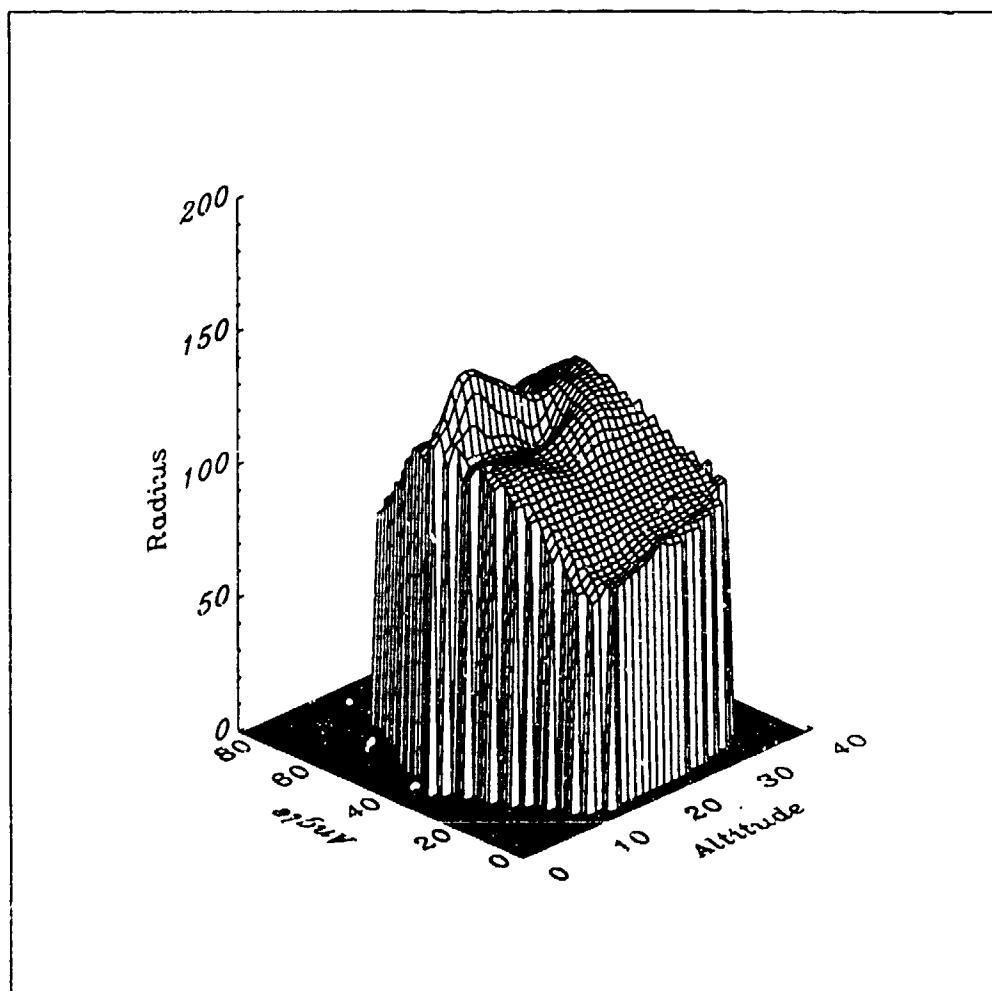
Updated Surface After Subject 142



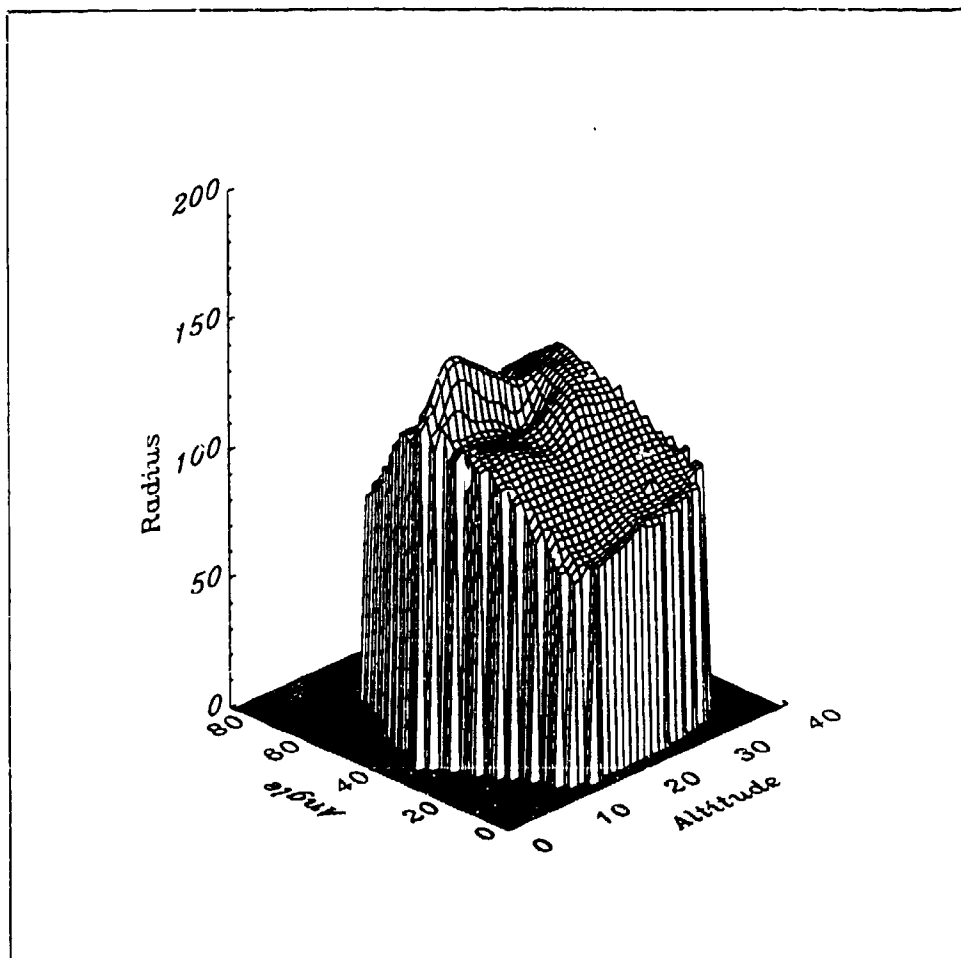
Updated Surface After Subject 153



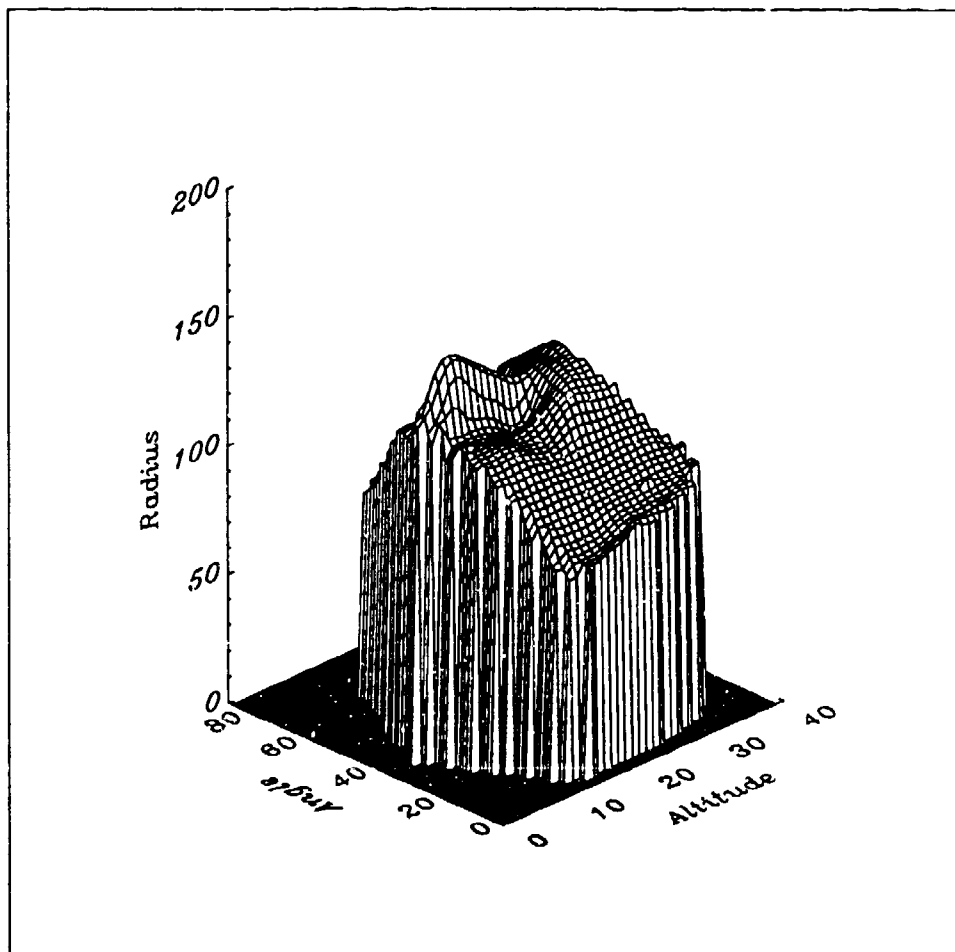
Updated Surface After Subject 154



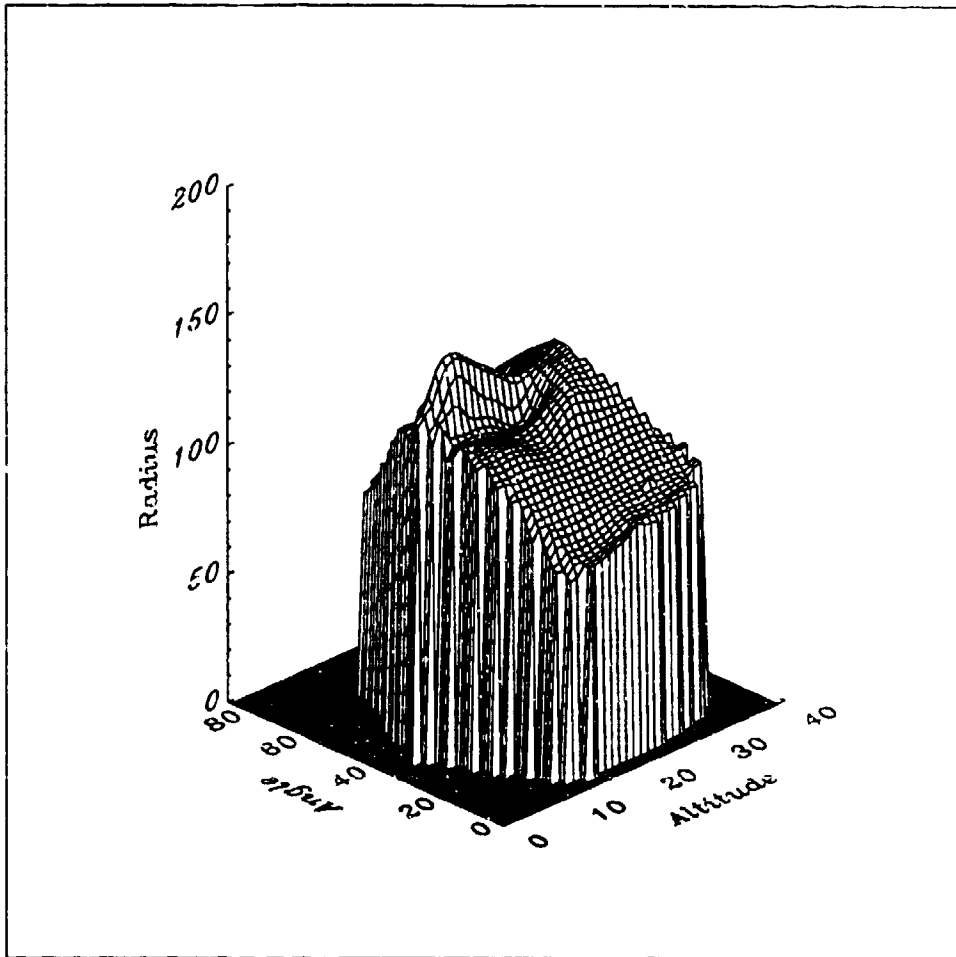
Updated Surface After Subject 155



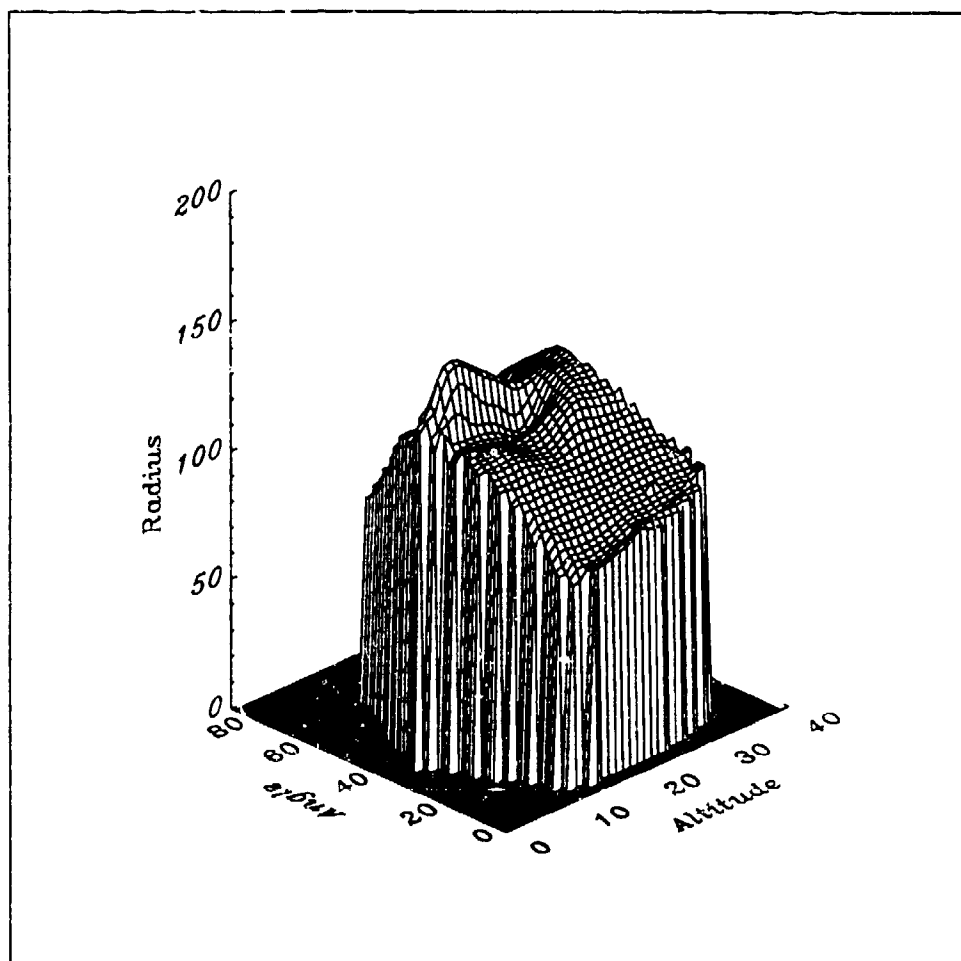
Updated Surface After Subject 159



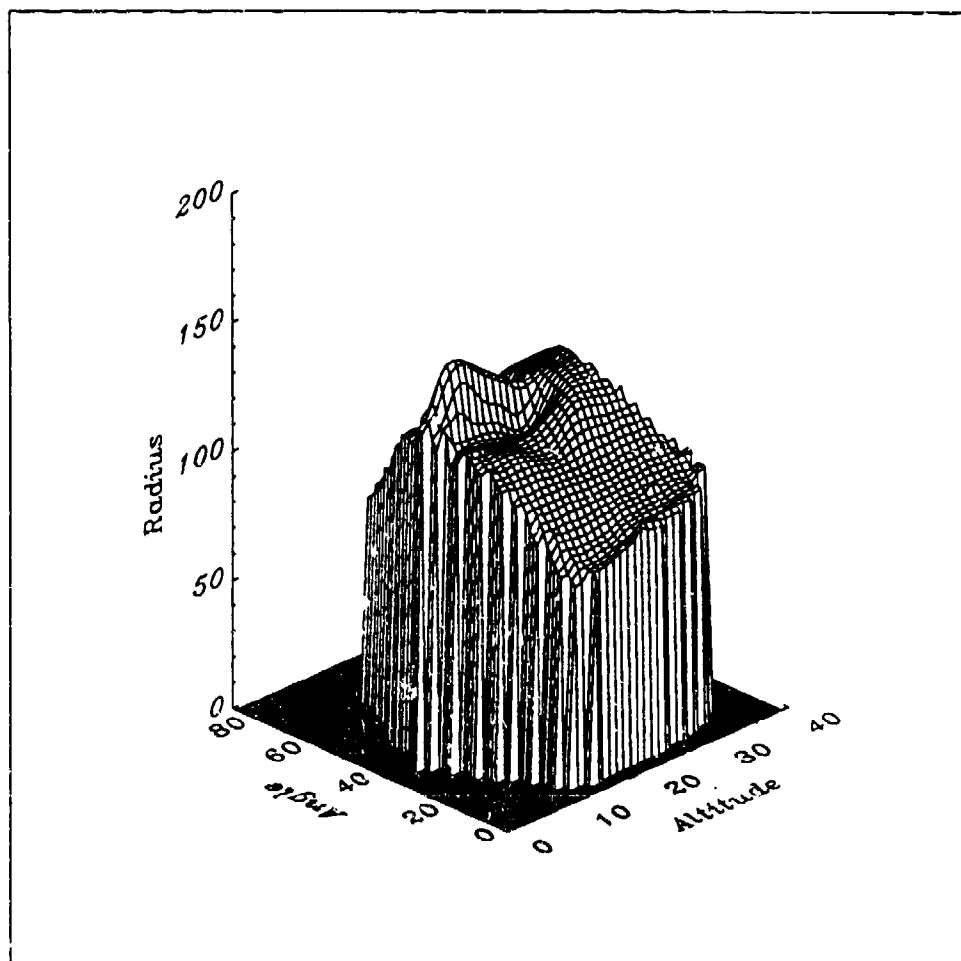
Updated Surface After Subject 160



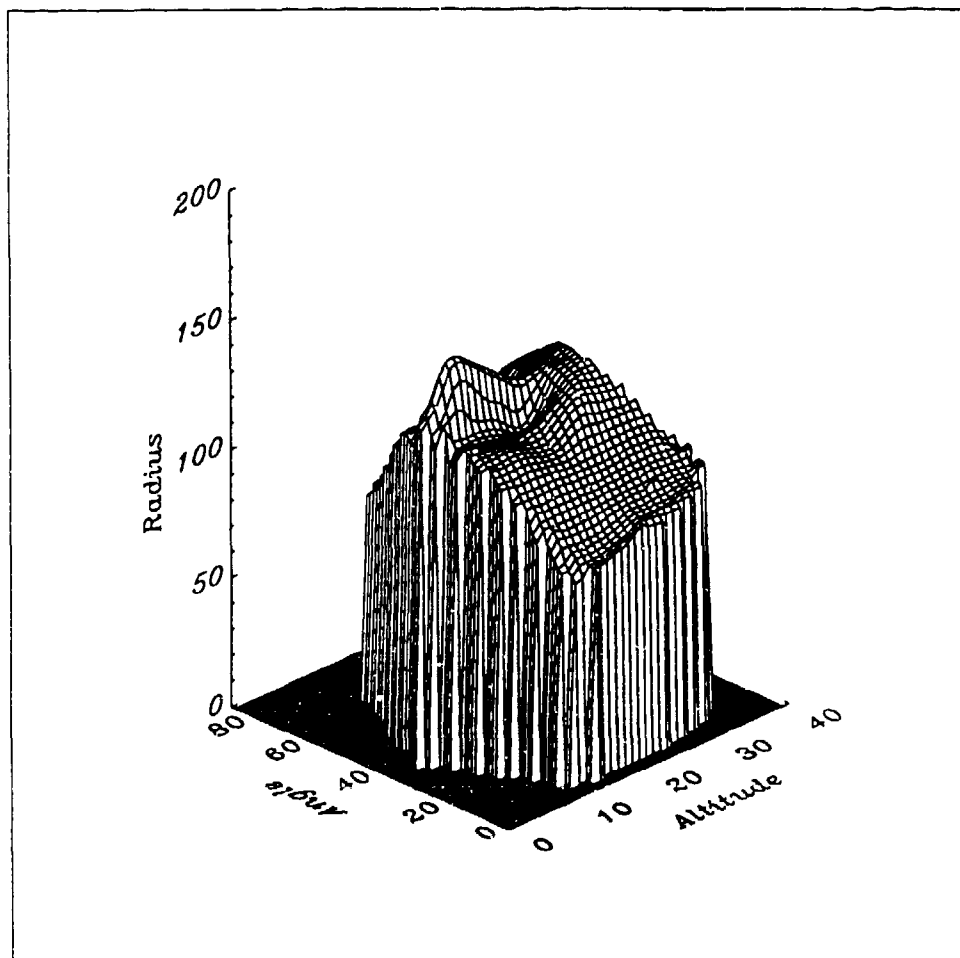
Updated Surface After Subject 161



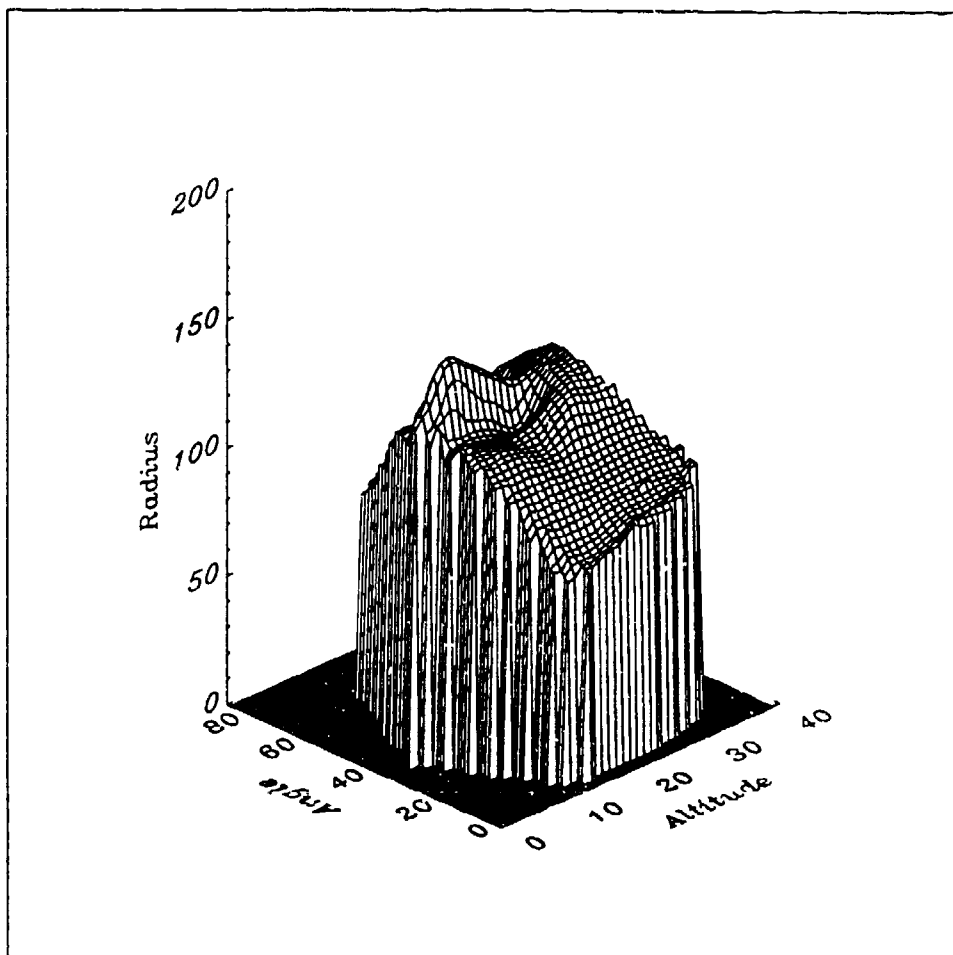
Updated Surface After Subject 167



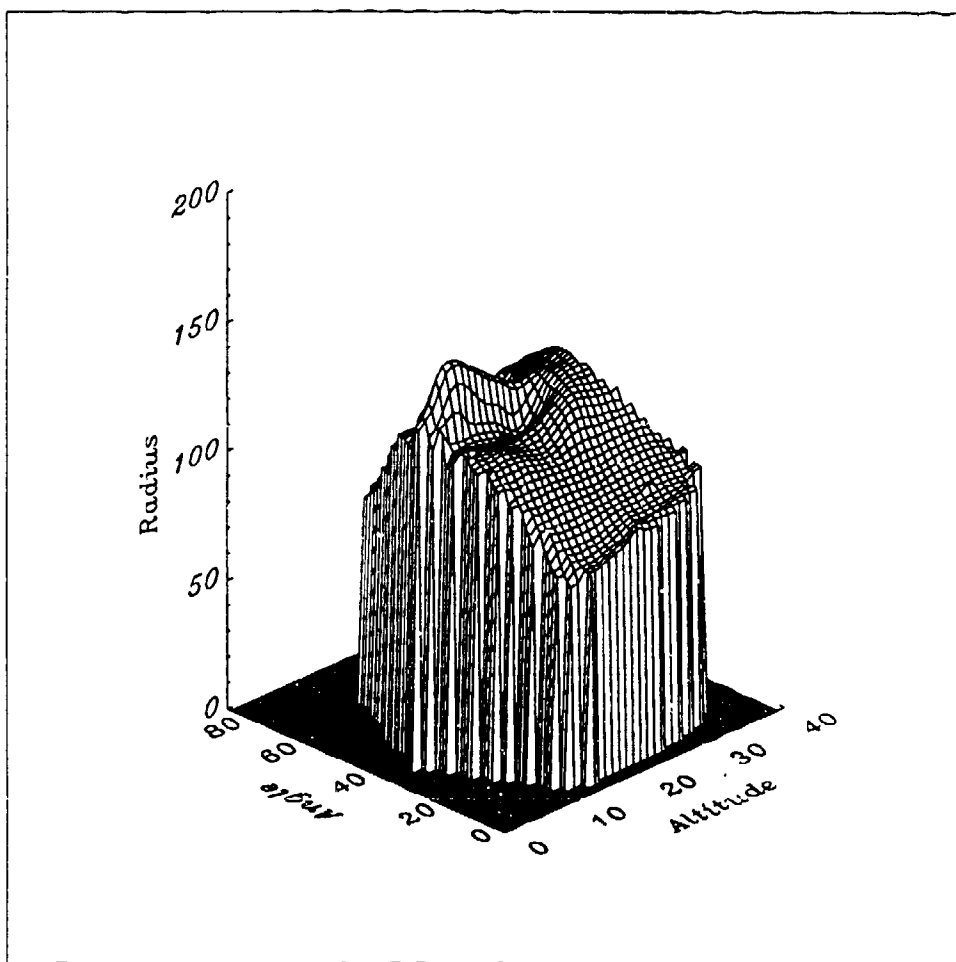
Updated Surface After Subject 171



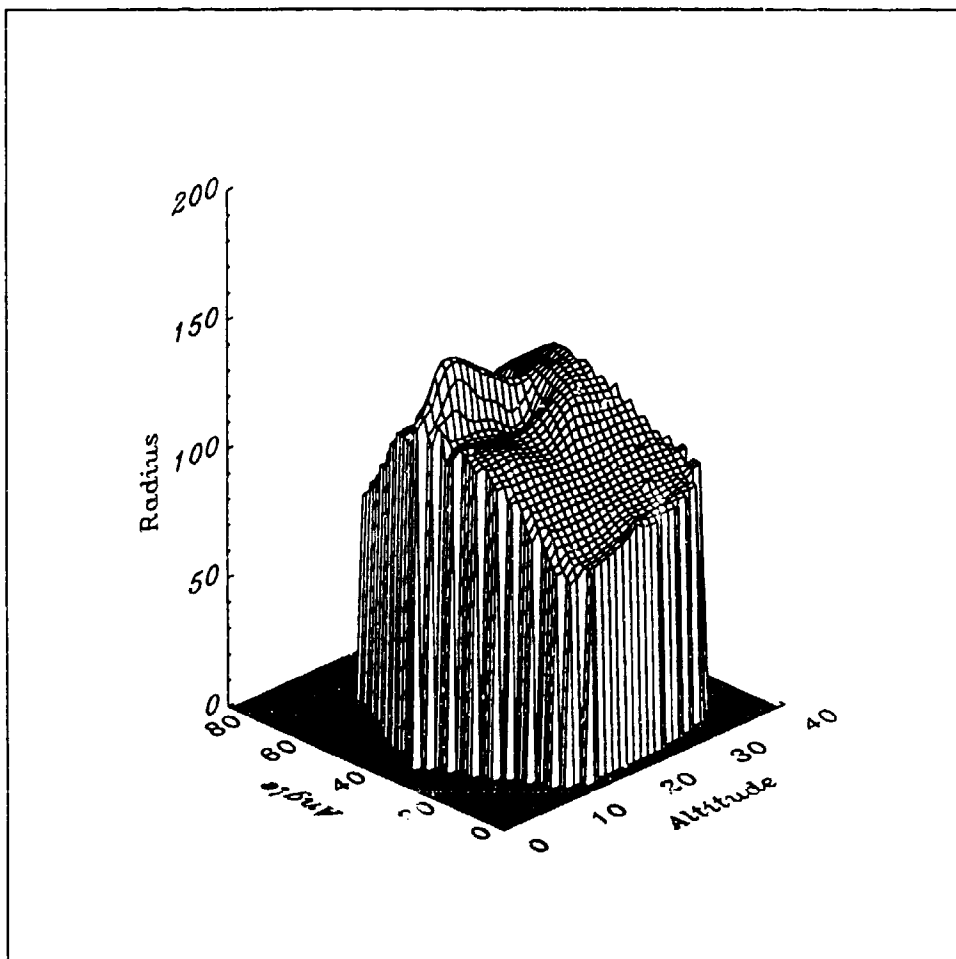
Updated Surface After Subject 173



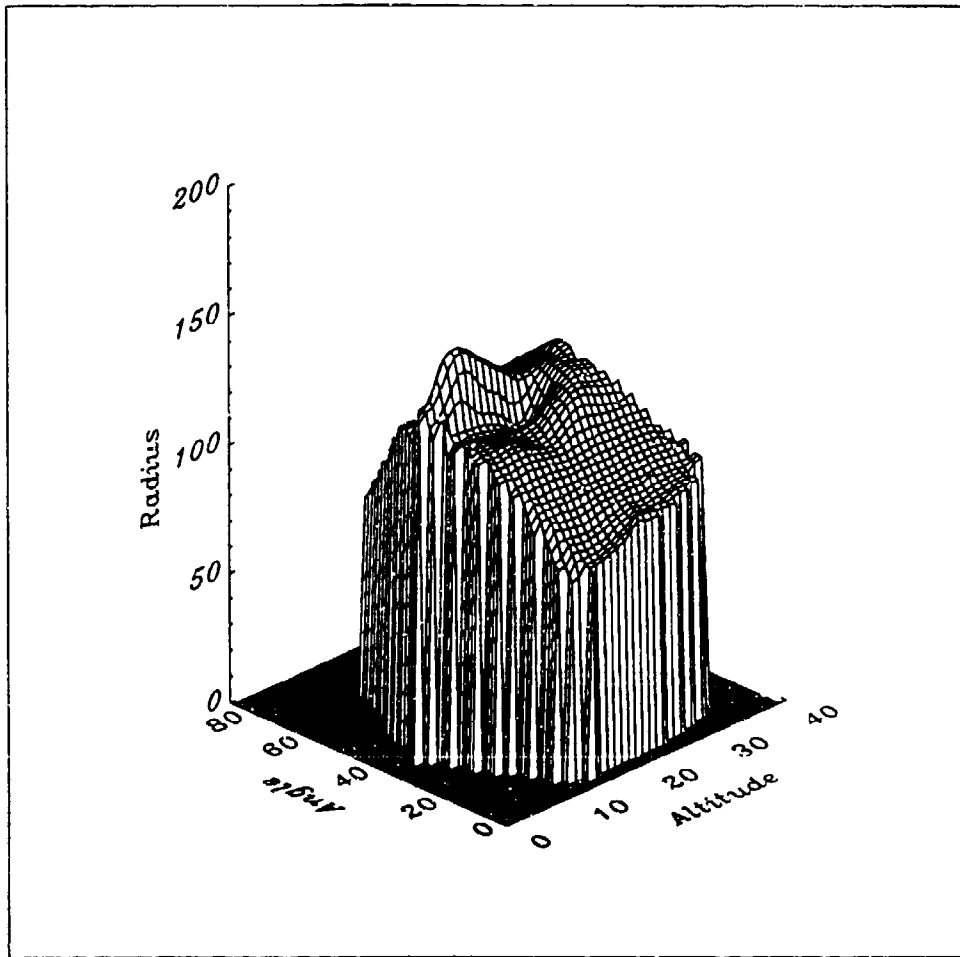
Updated Surface After Subject 176



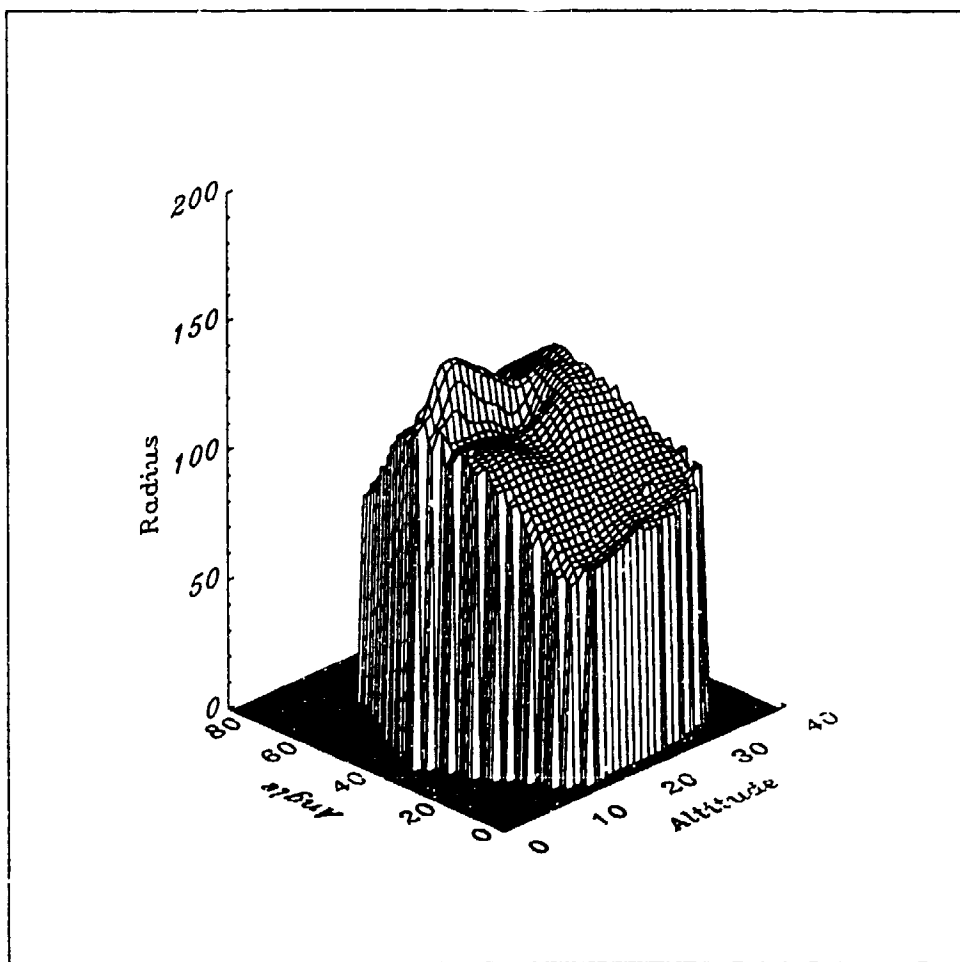
Updated Surface After Subject 183



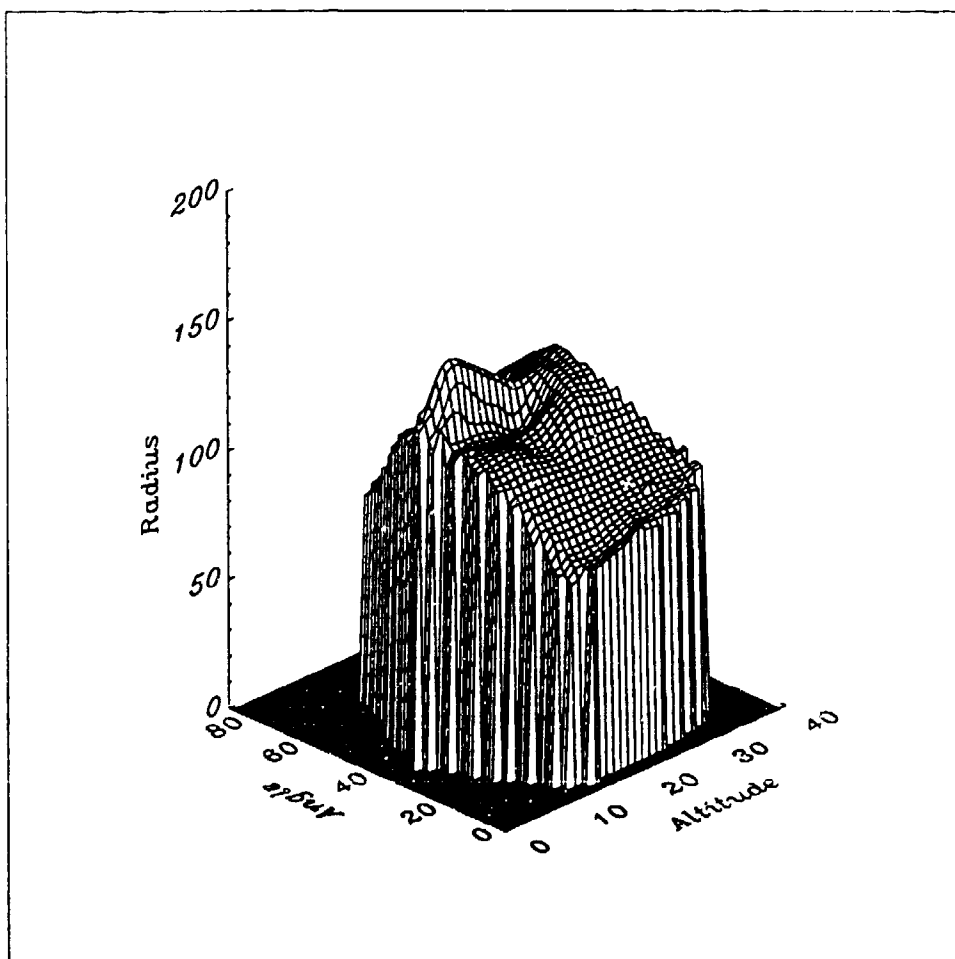
Updated Surface After Subject 185



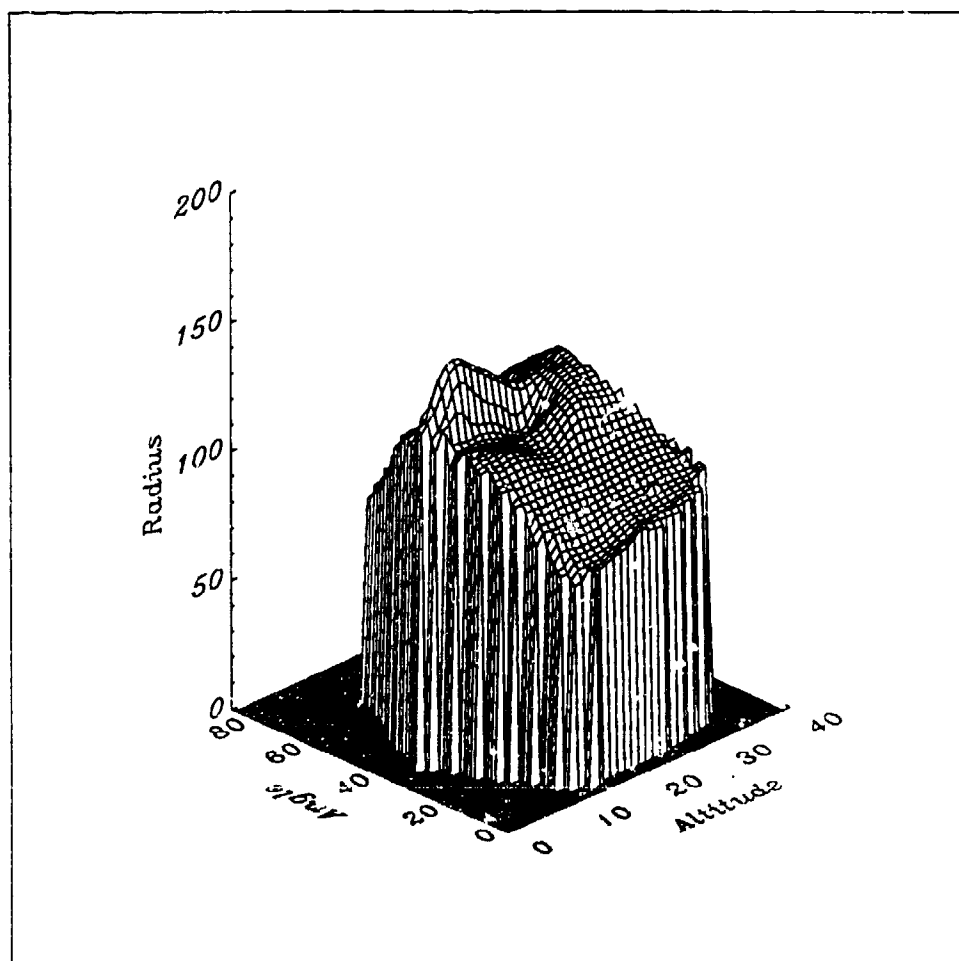
Updated Surface After Subject 112



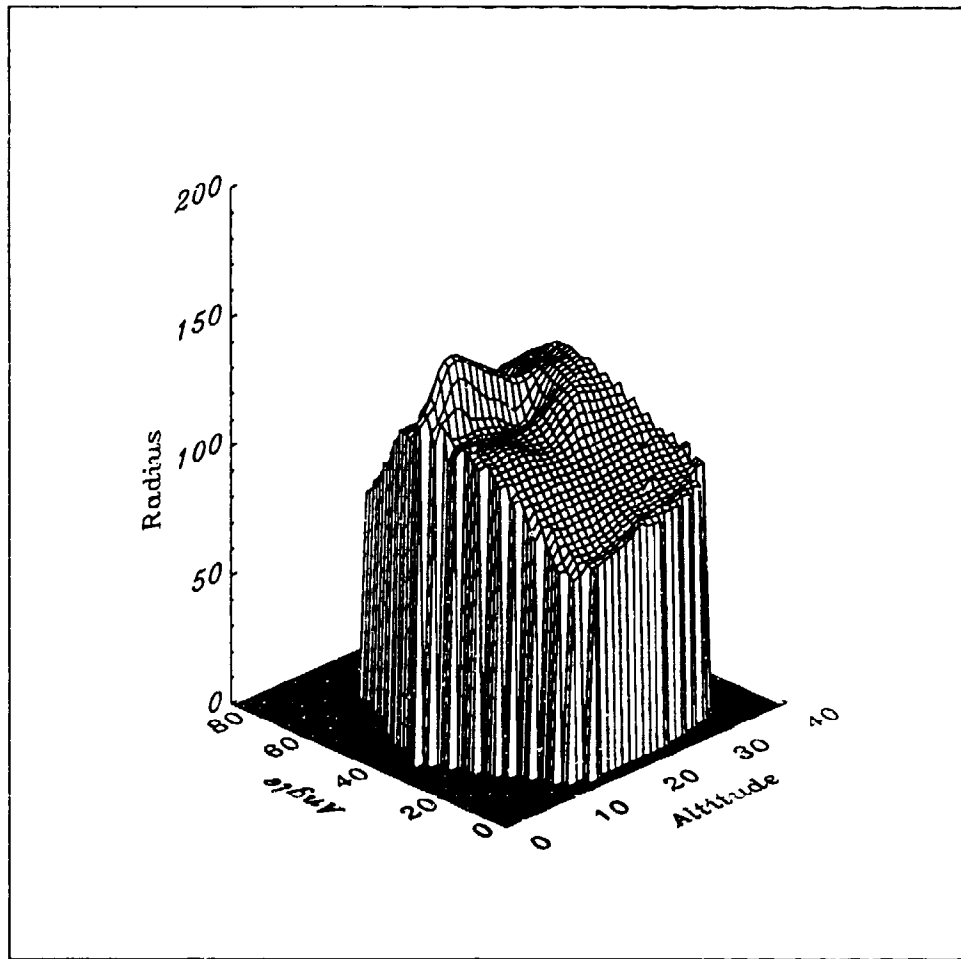
Updated Surface After Subject 141



Updated Surface After Subject 152



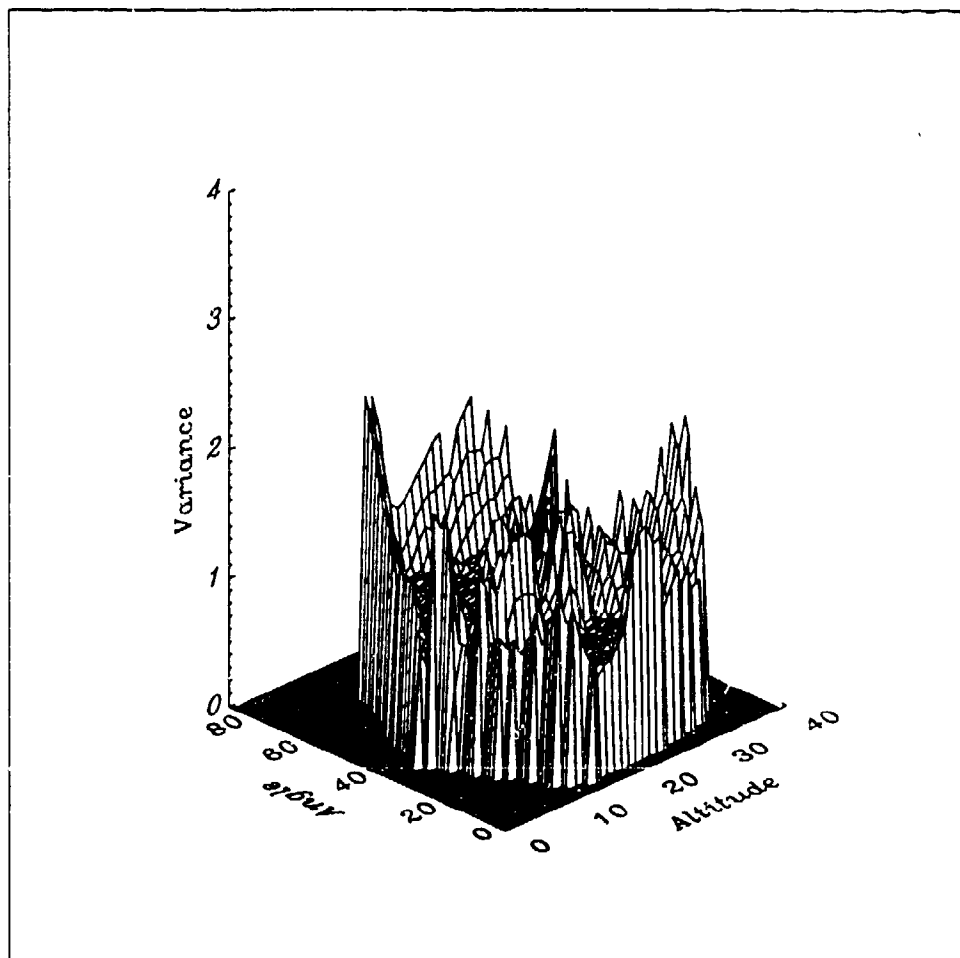
Updated Surface After Subject 156



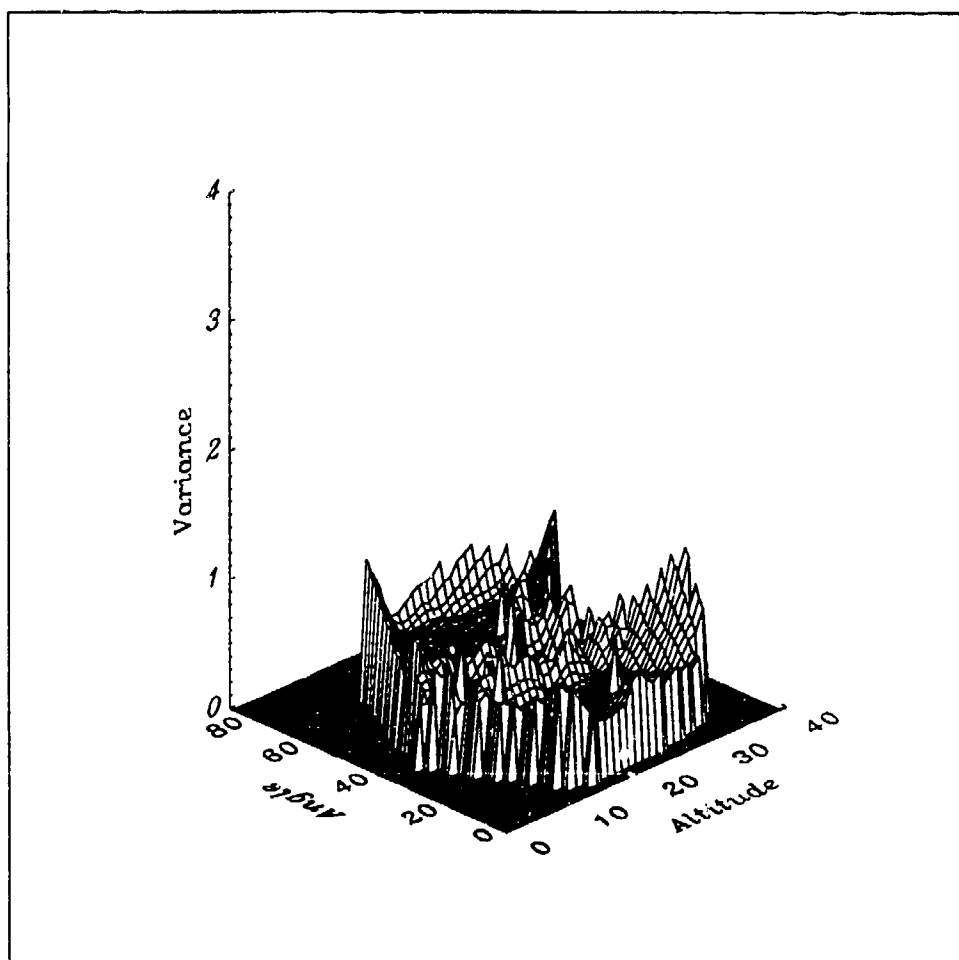
Updated Surface After Subject 199

### *Updated Estimation Variances*

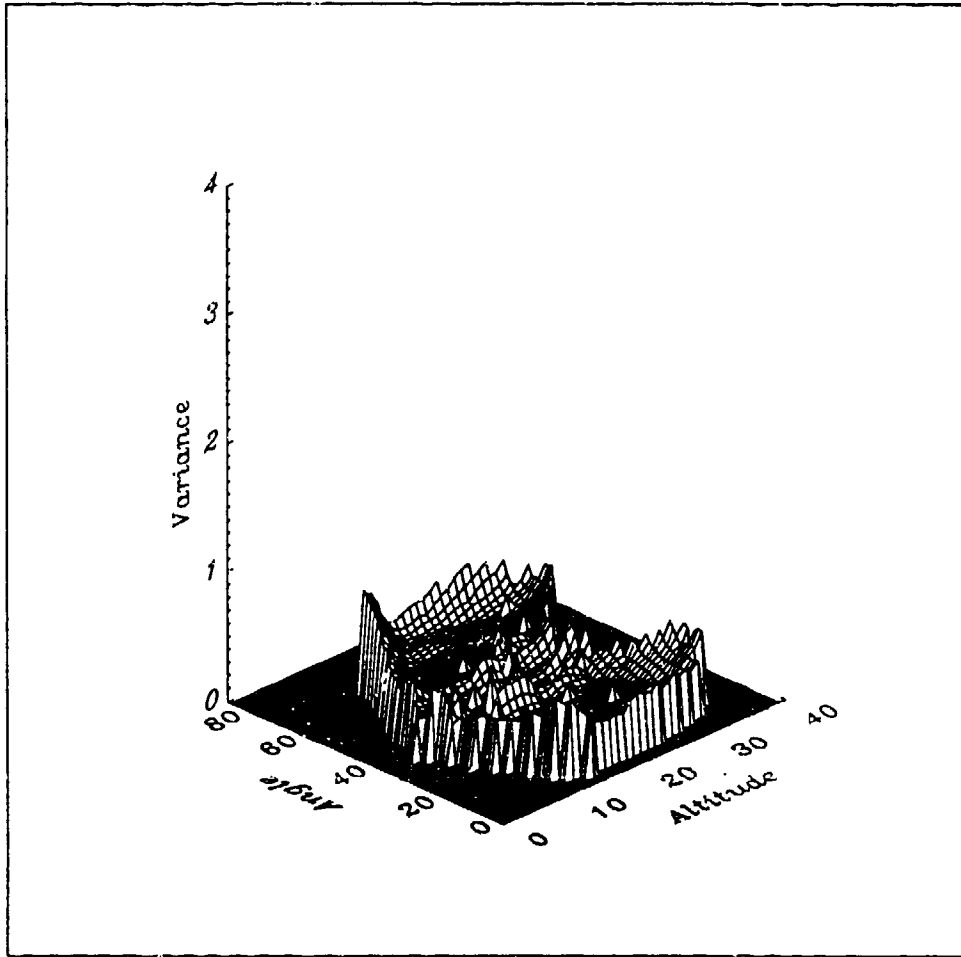
This section includes the plots of the variances.



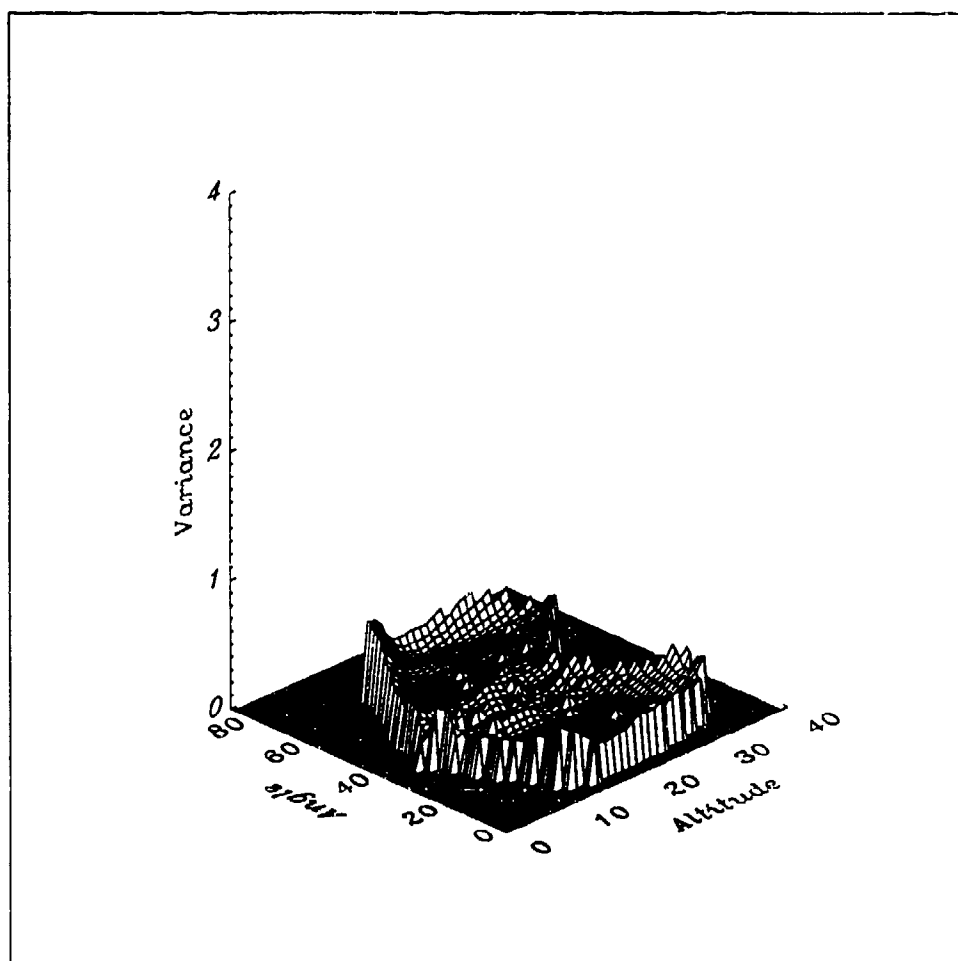
Updated Variances After Subject 09



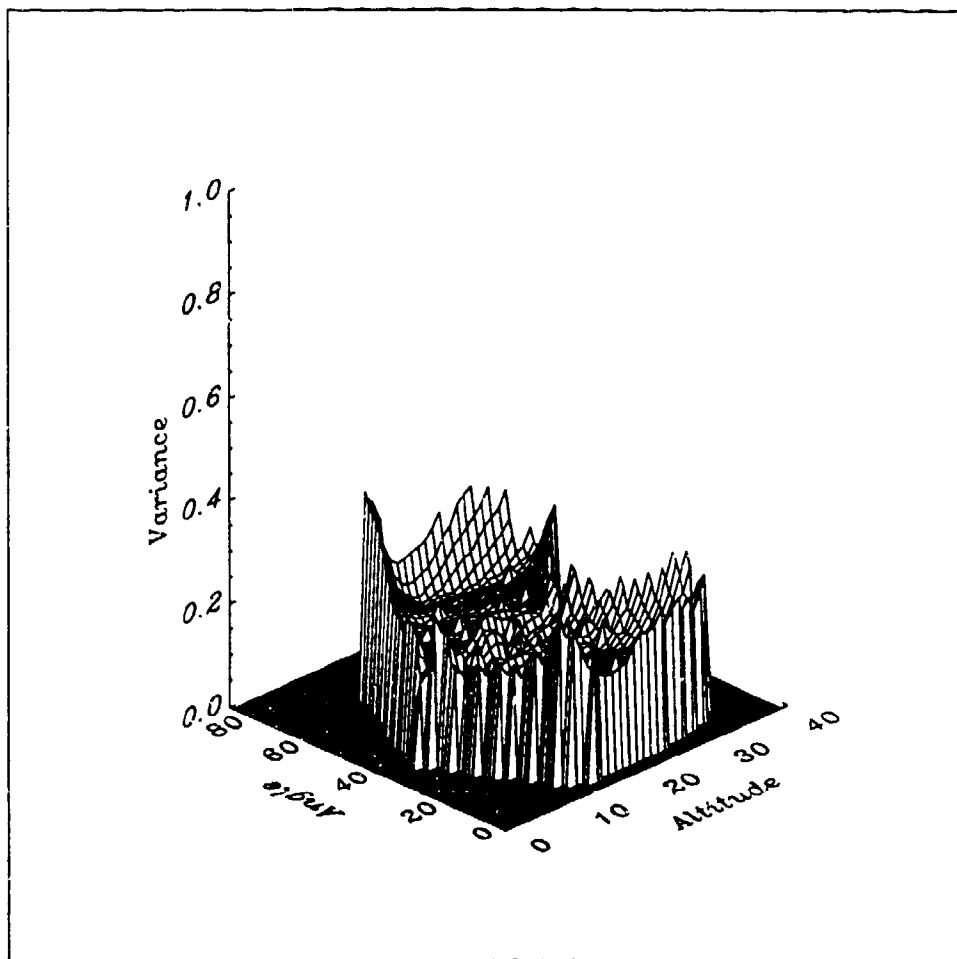
Updated Variances After Subject 10



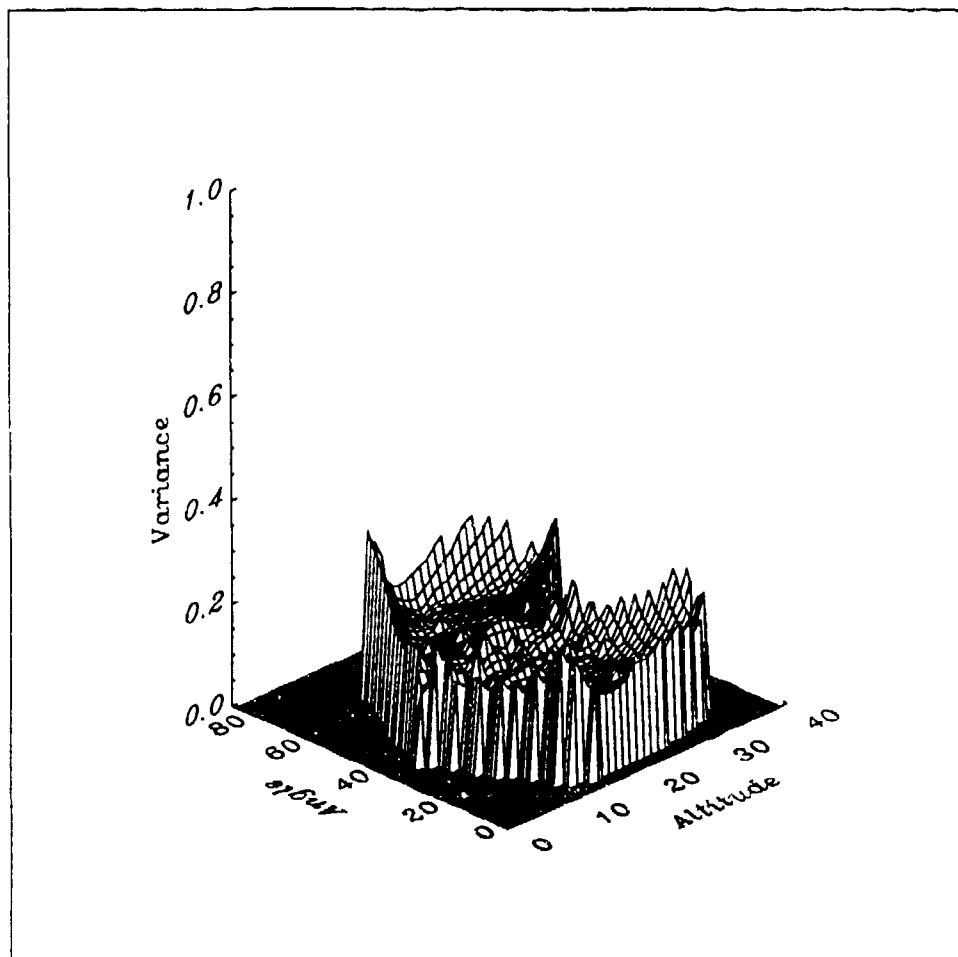
Updated Variances After Subject 60



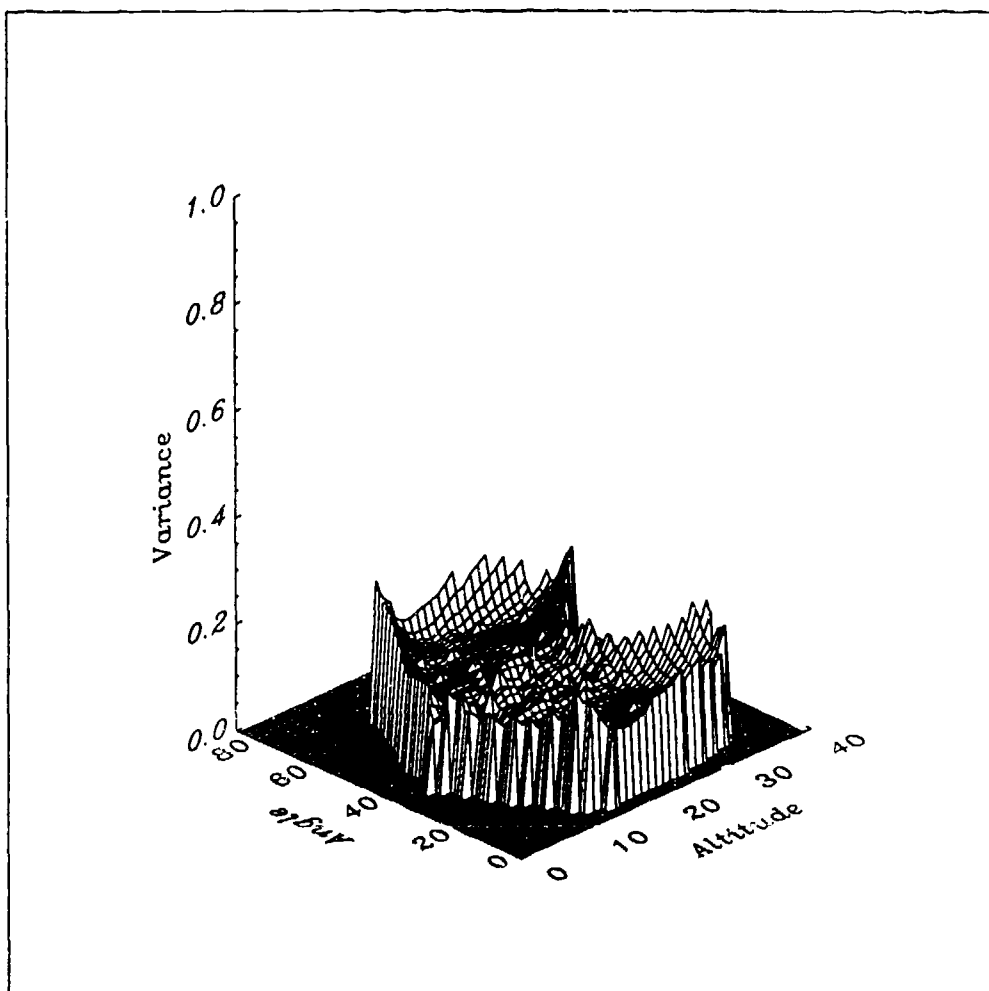
Updated Variances After Subject 68



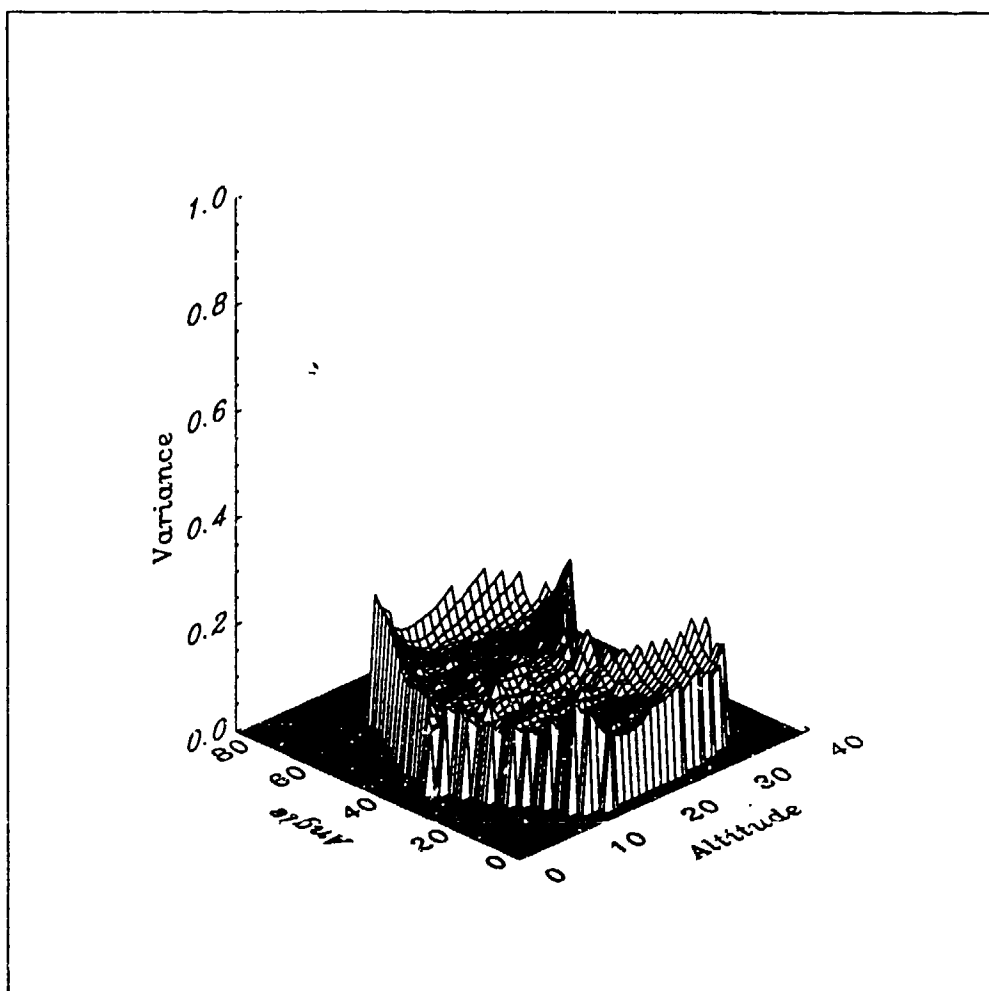
Updated Variances After Subject 114



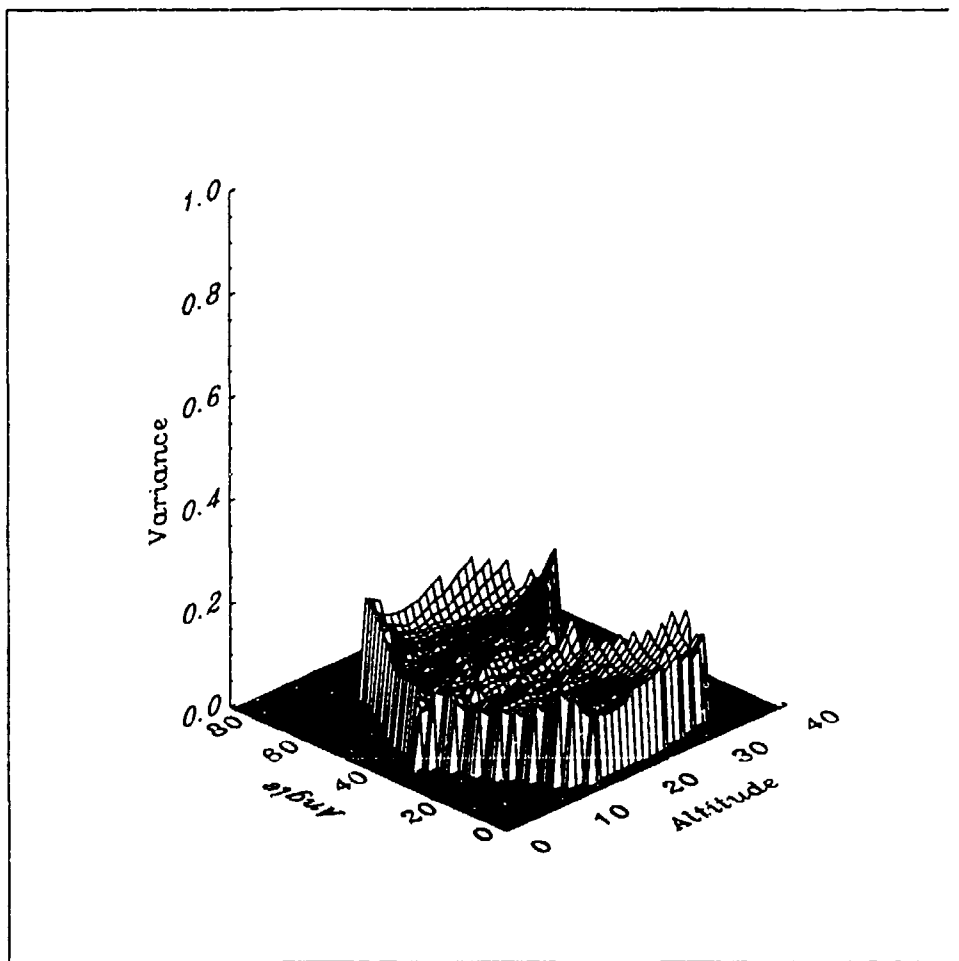
Updated Variances After Subject 116



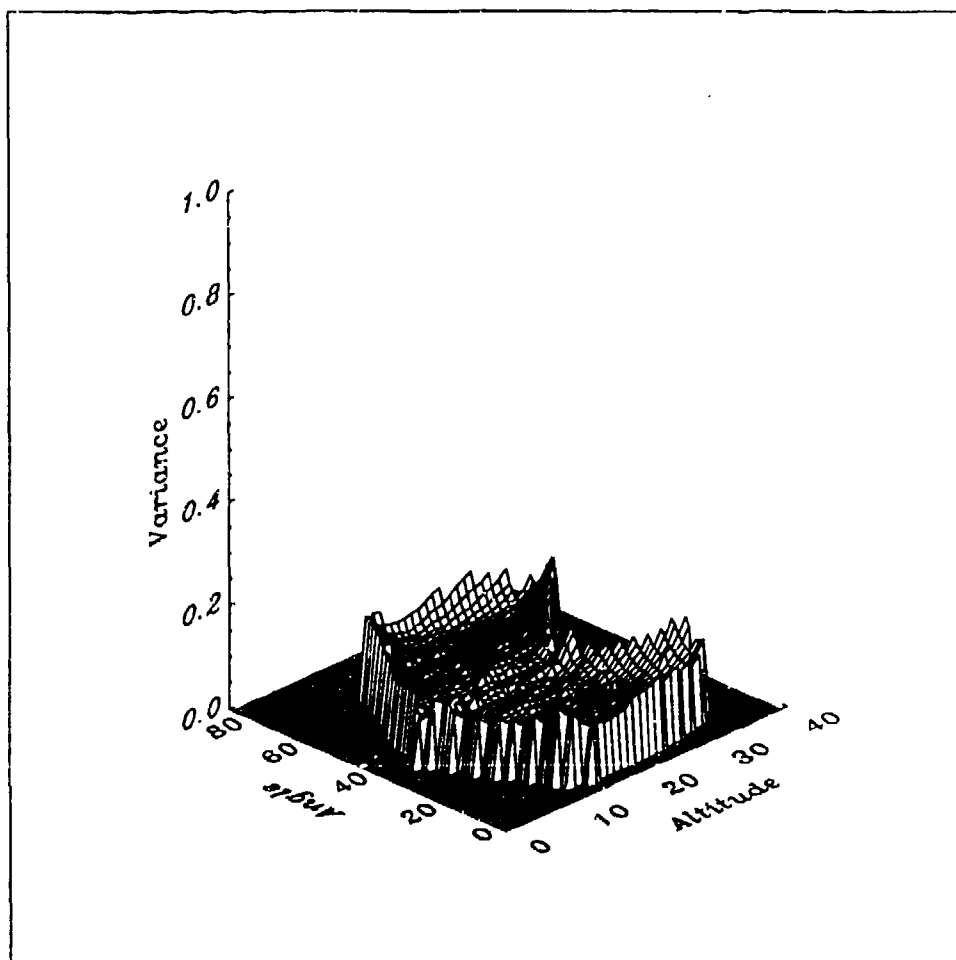
Updated Variances After Subject 118



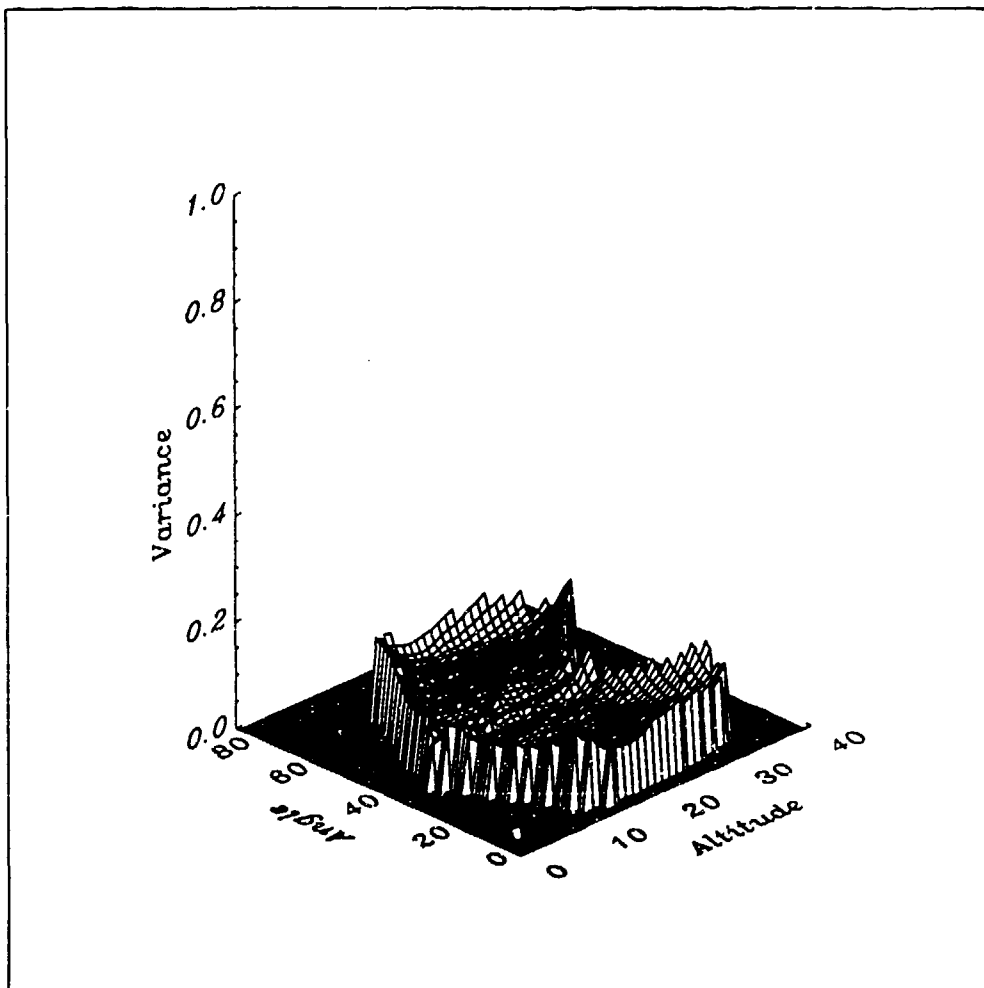
Updated Variances After Subject 122



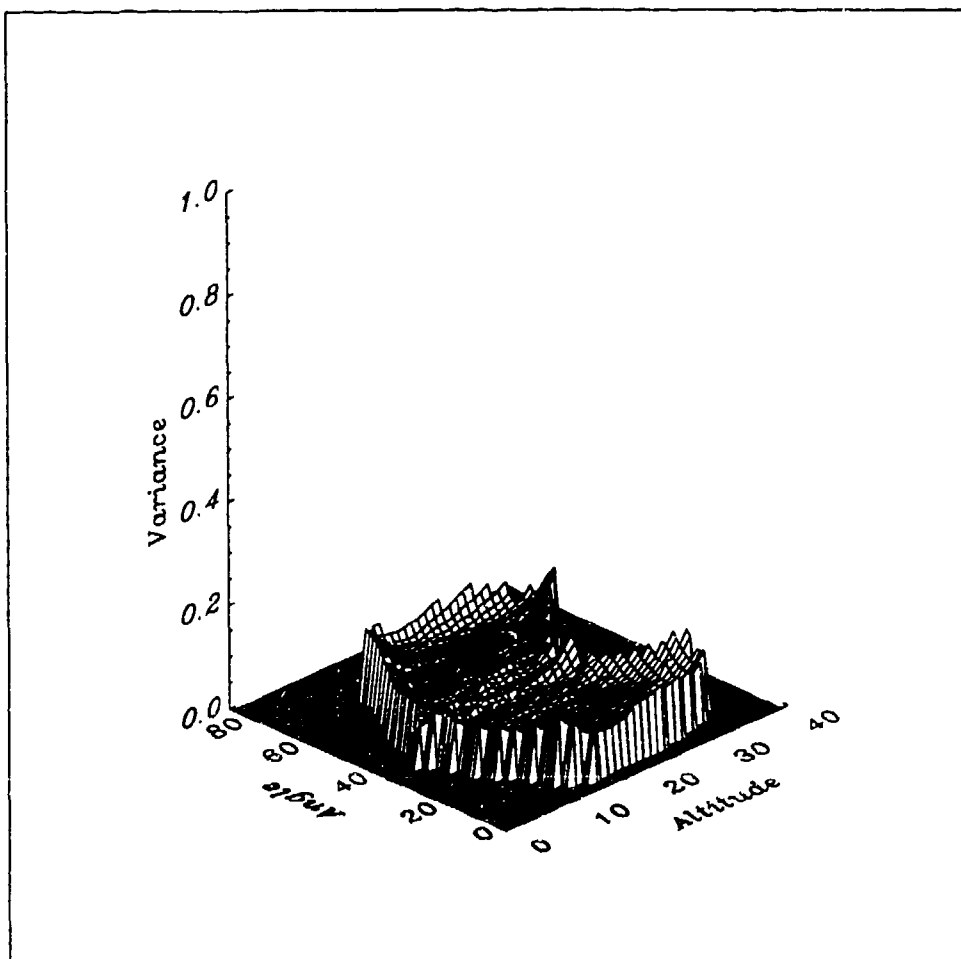
Updated Variances After Subject 130



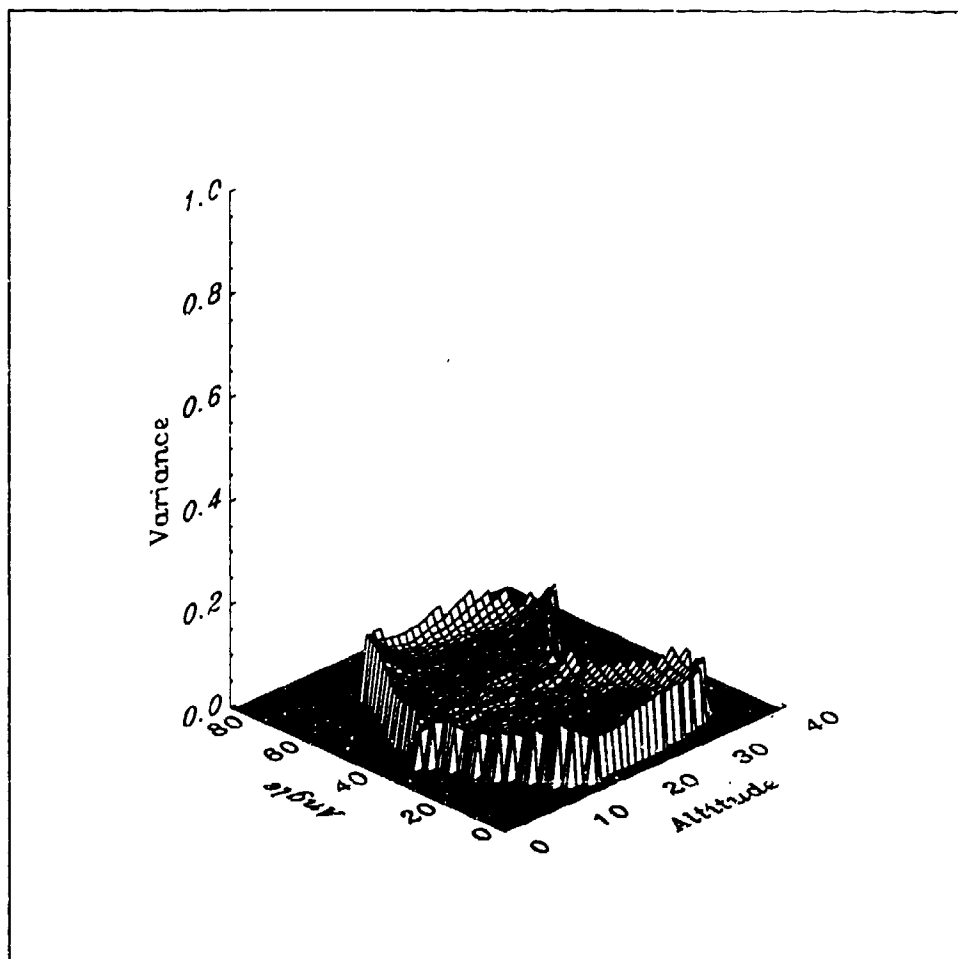
Updated Variances After Subject 133



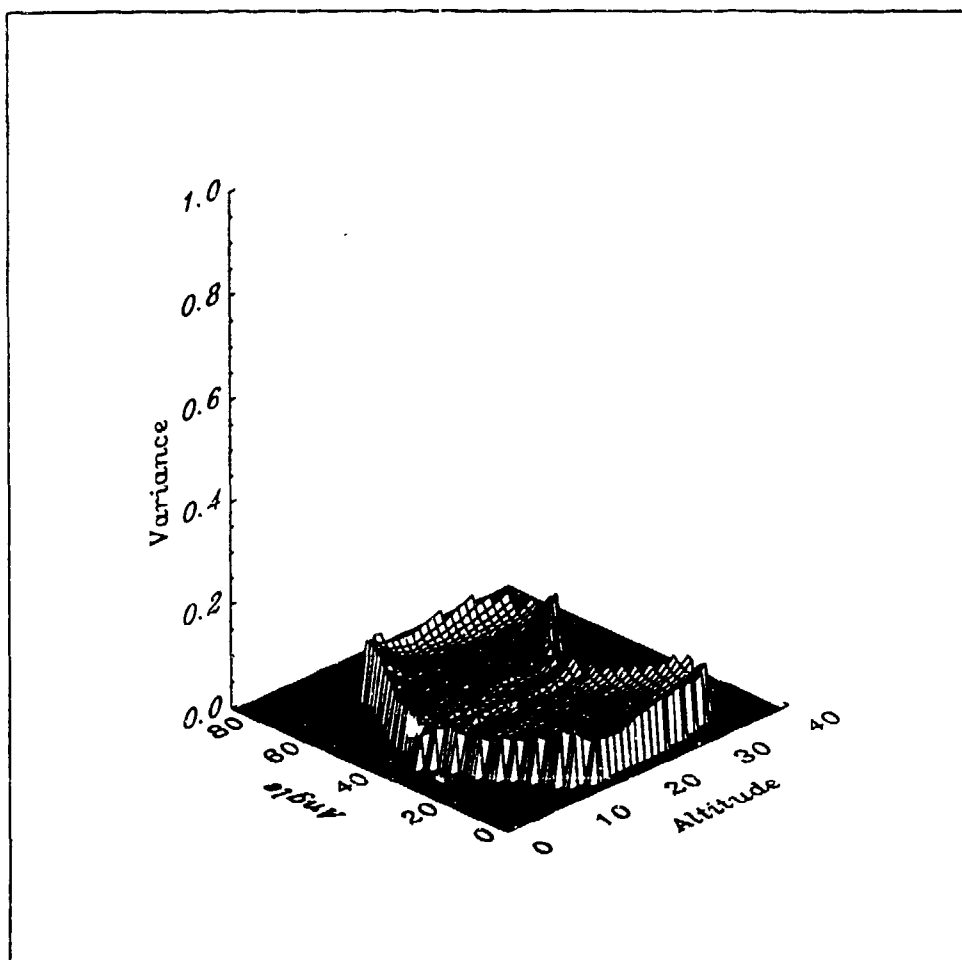
Updated Variances After Subject 136



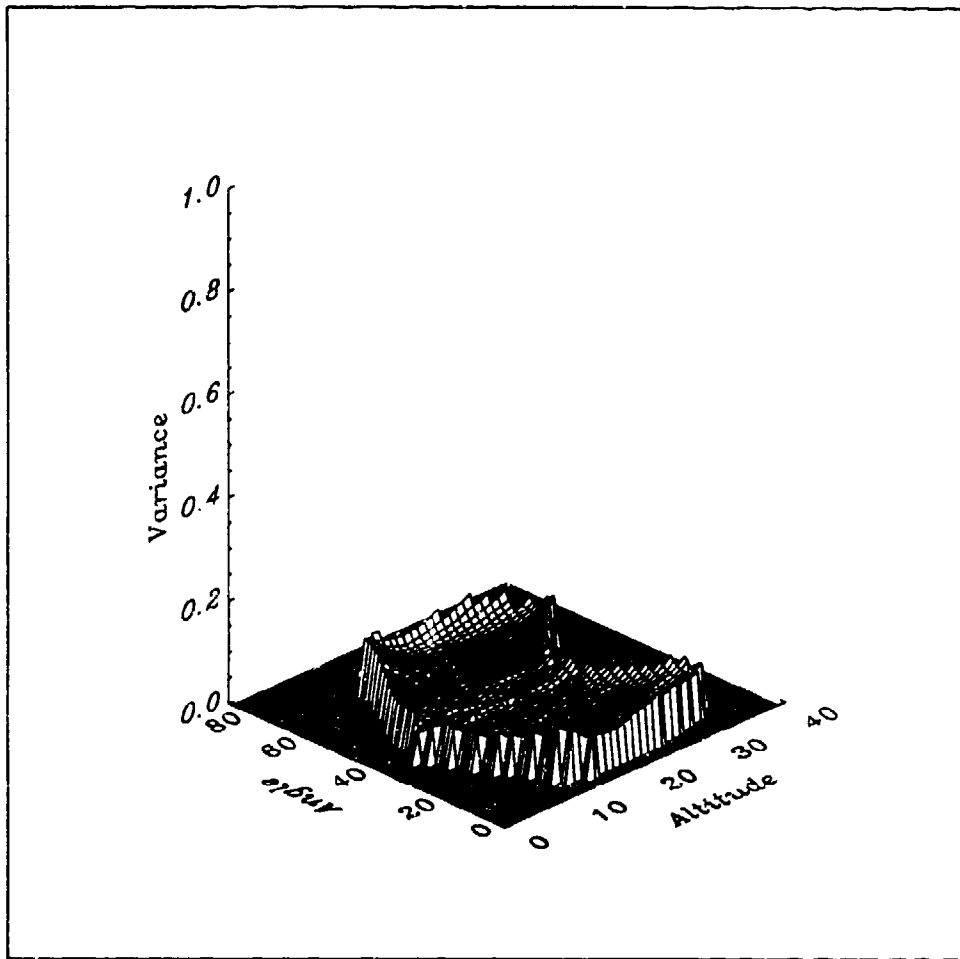
Updated Variances After Subject 140



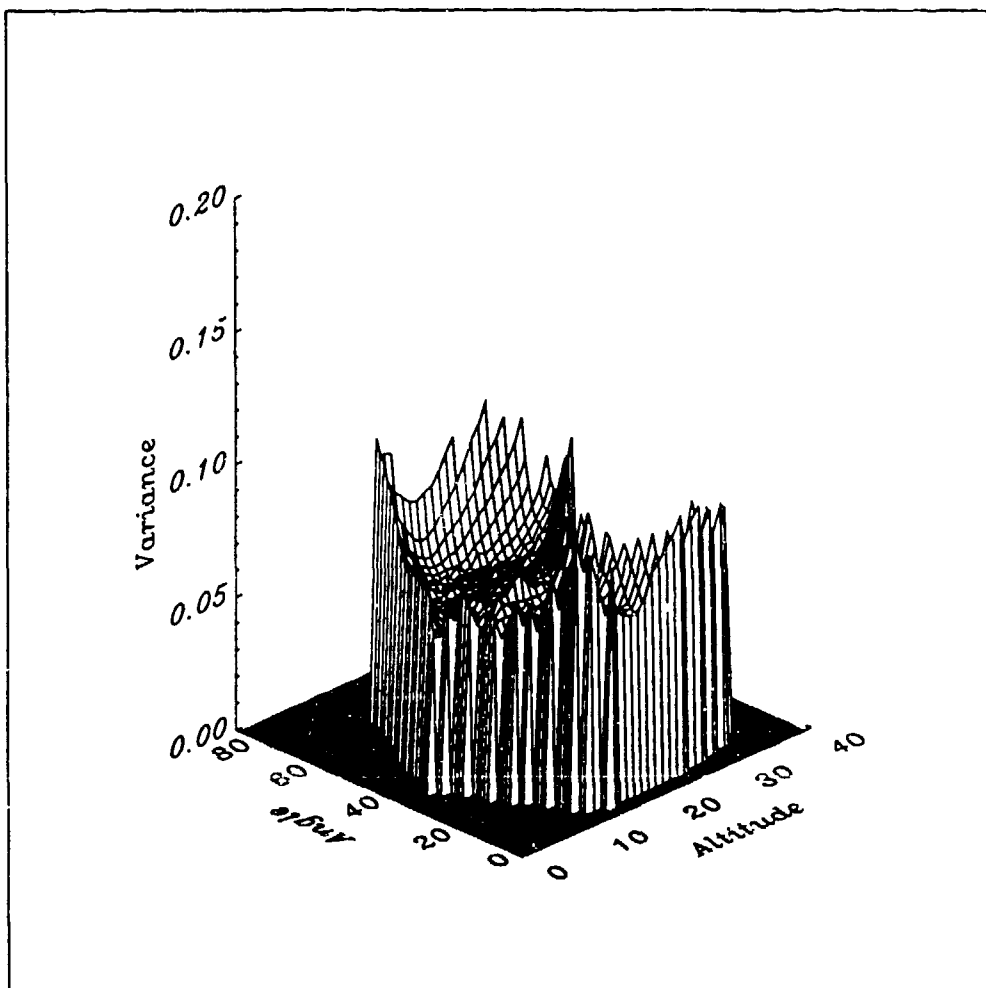
Updated Variances After Subject 142



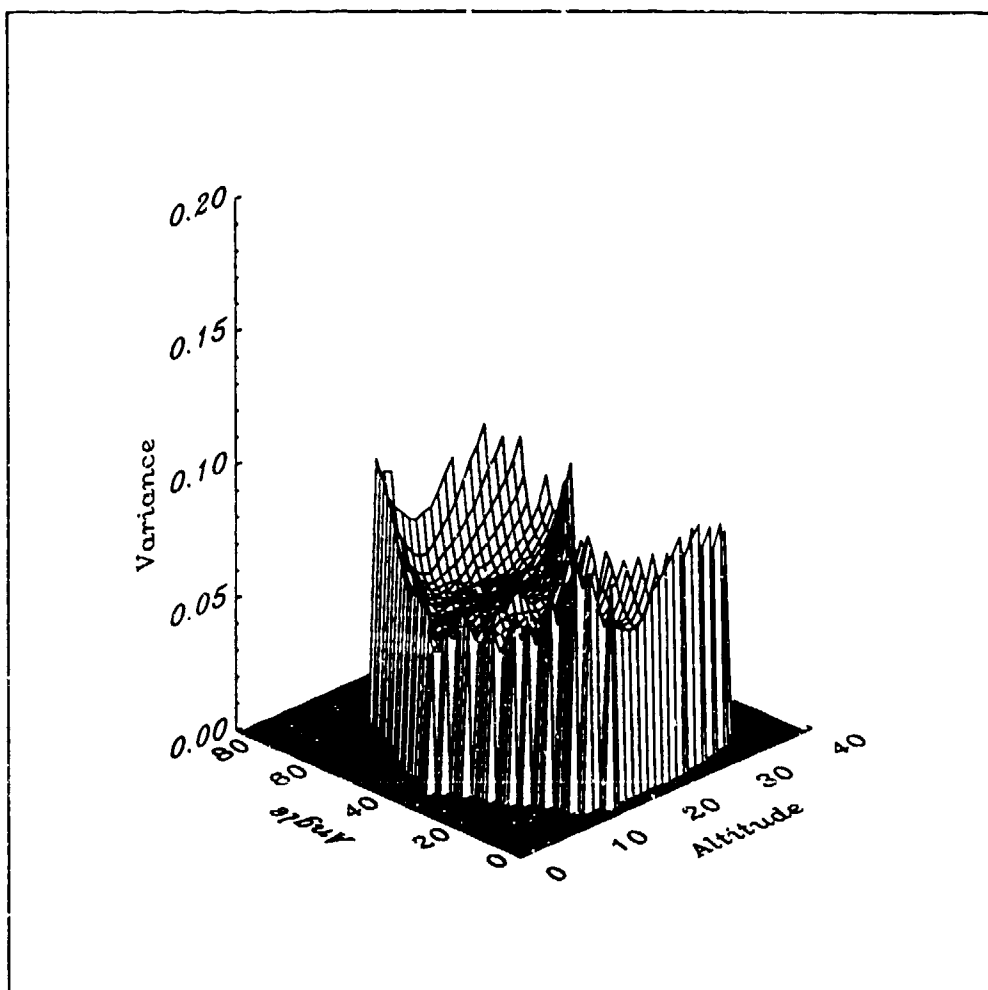
Updated Variances After Subject 153



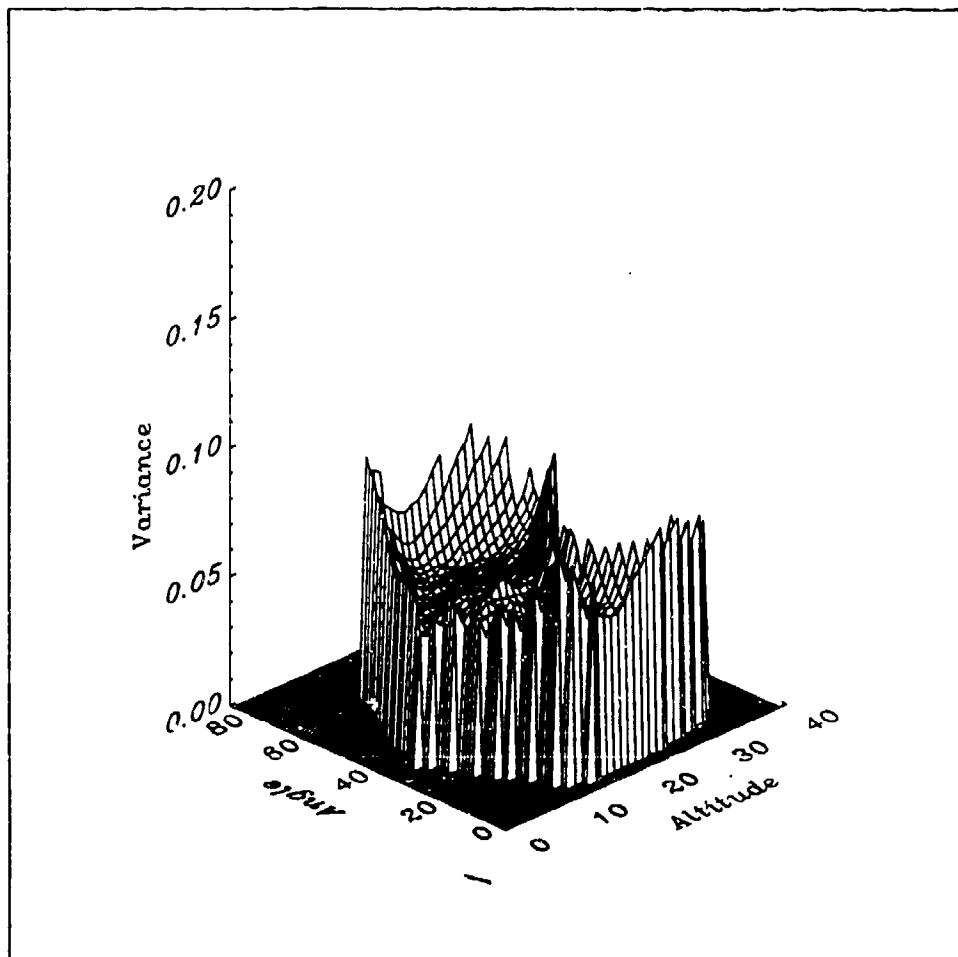
Updated Variances After Subject 154



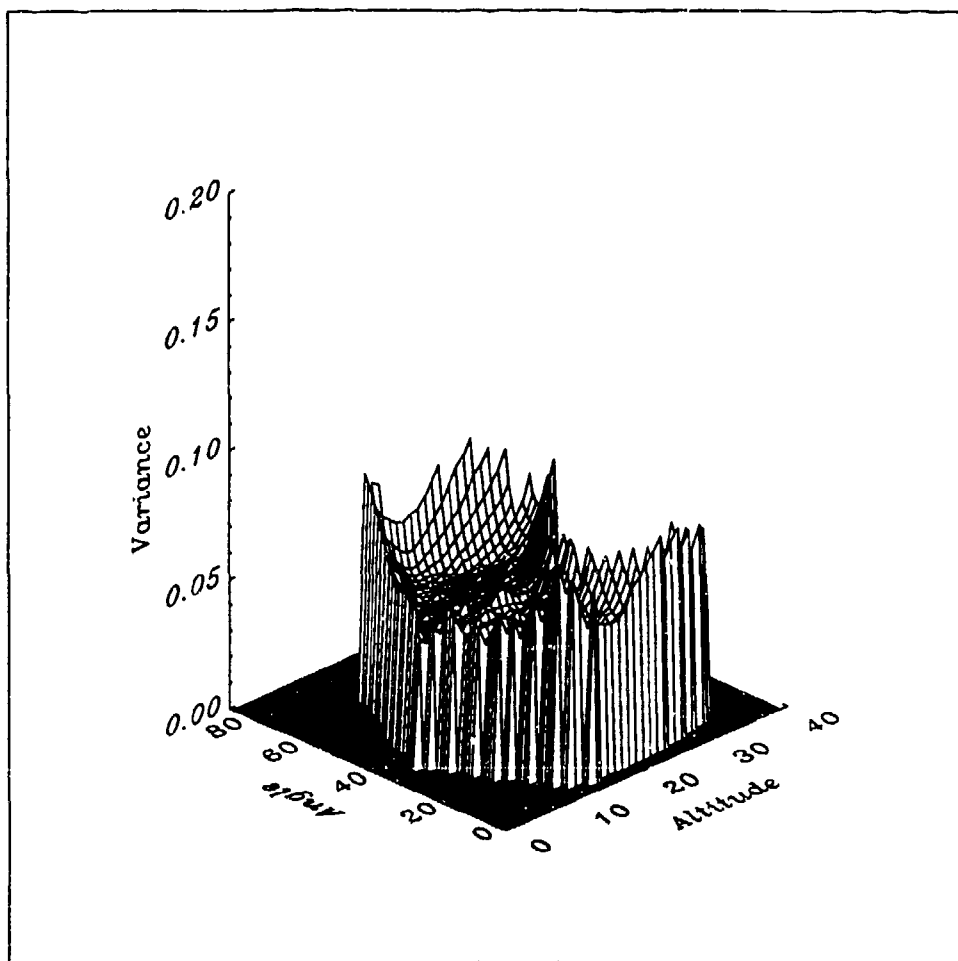
Updated Variances After Subject 155



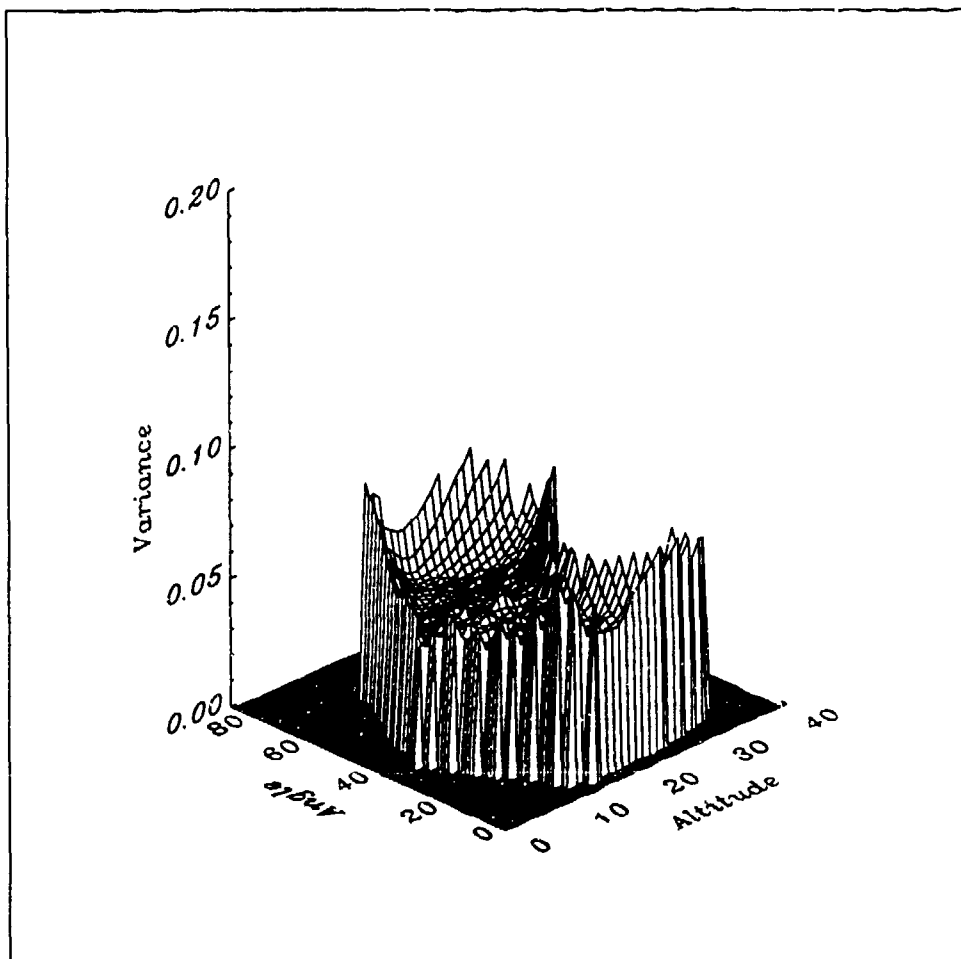
Updated Variances After Subject 159



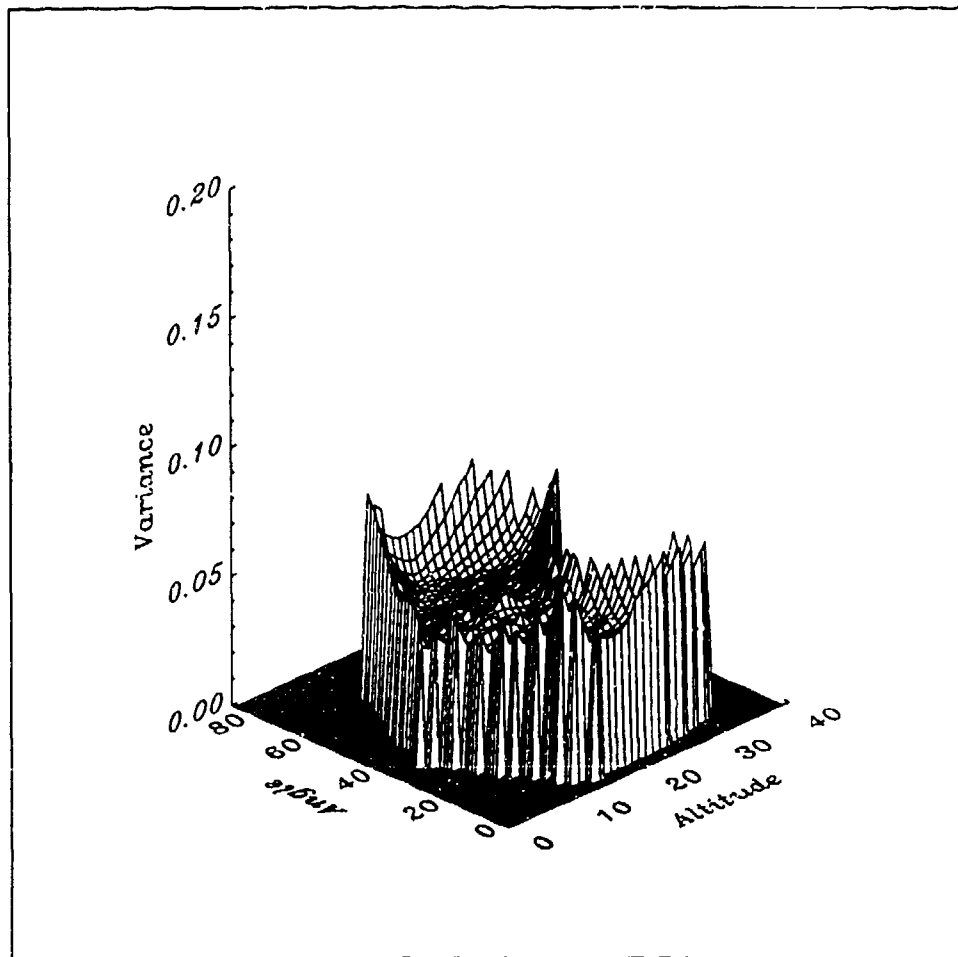
Updated Variances After Subject 160



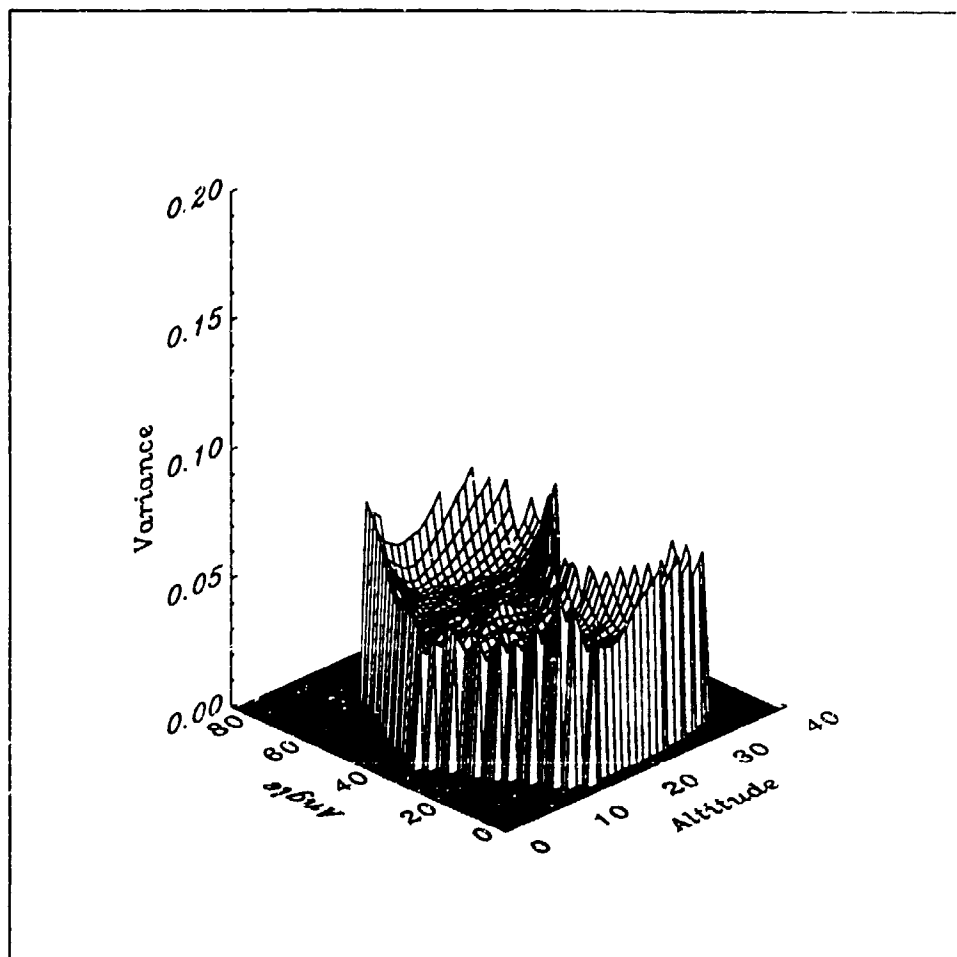
Updated Variances After Subject 161



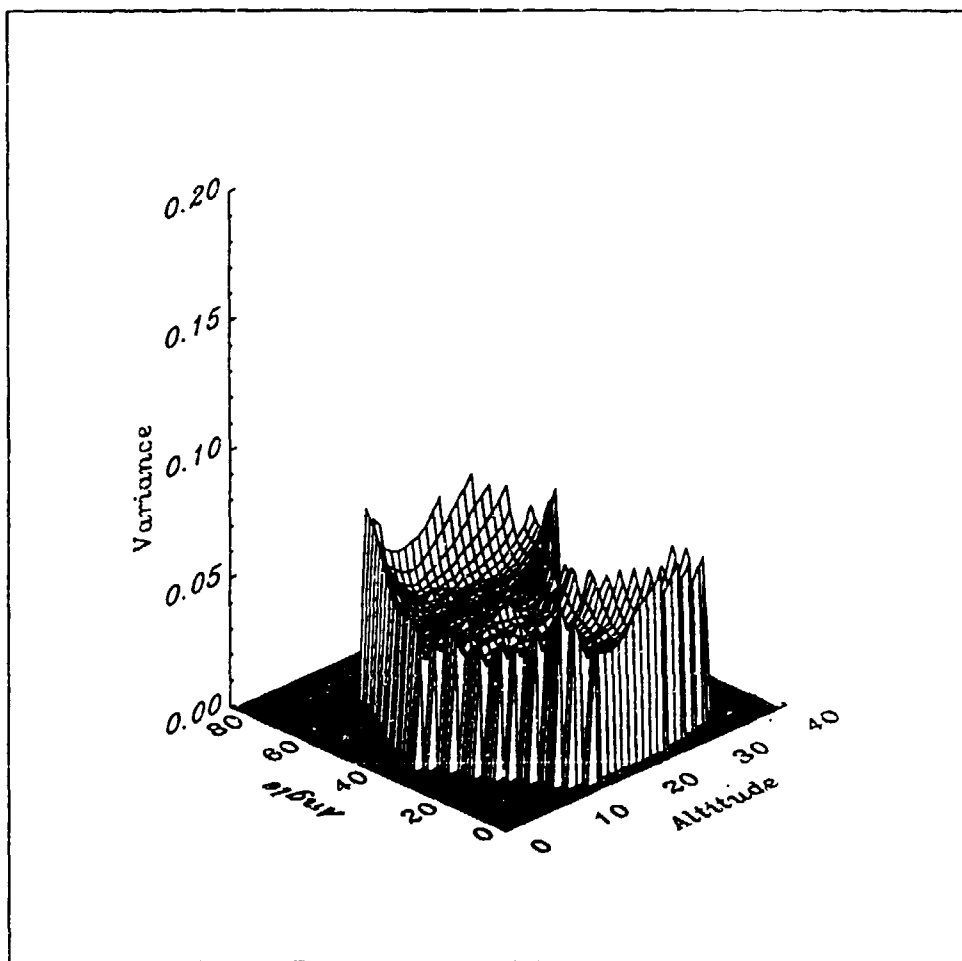
Updated Variances After Subject 167



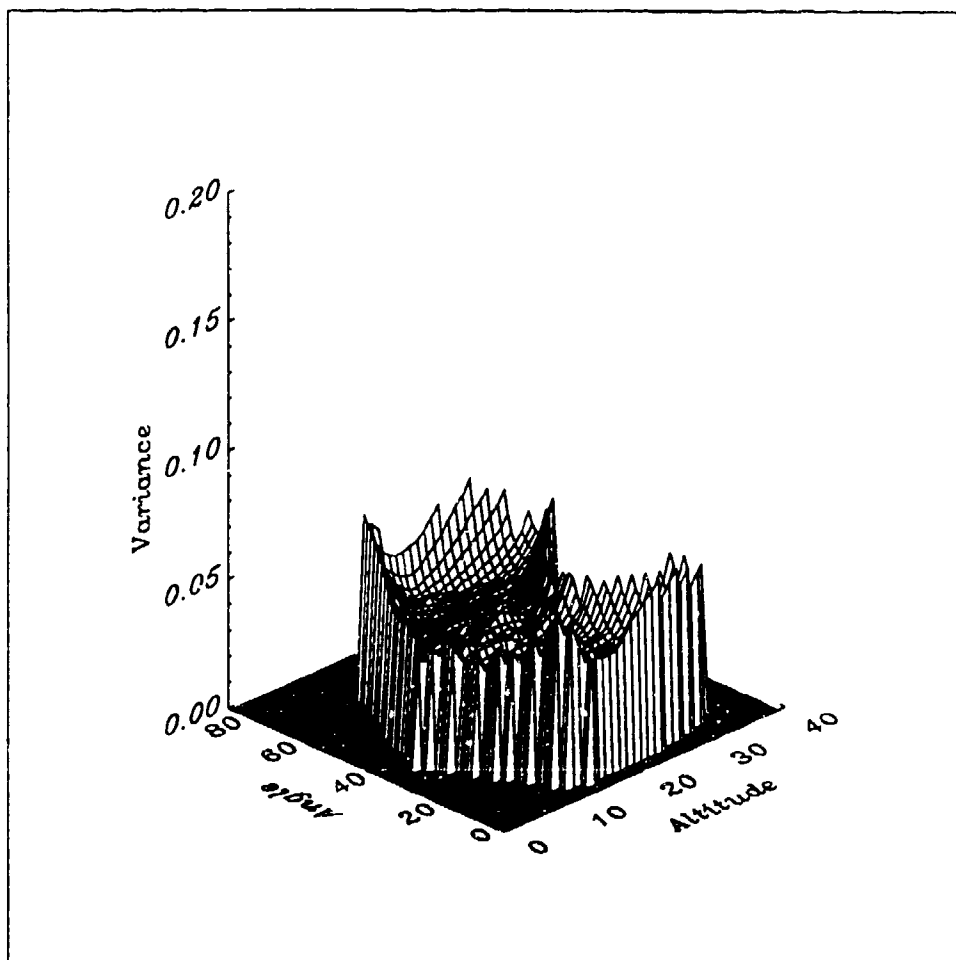
Updated Variances After Subject 171



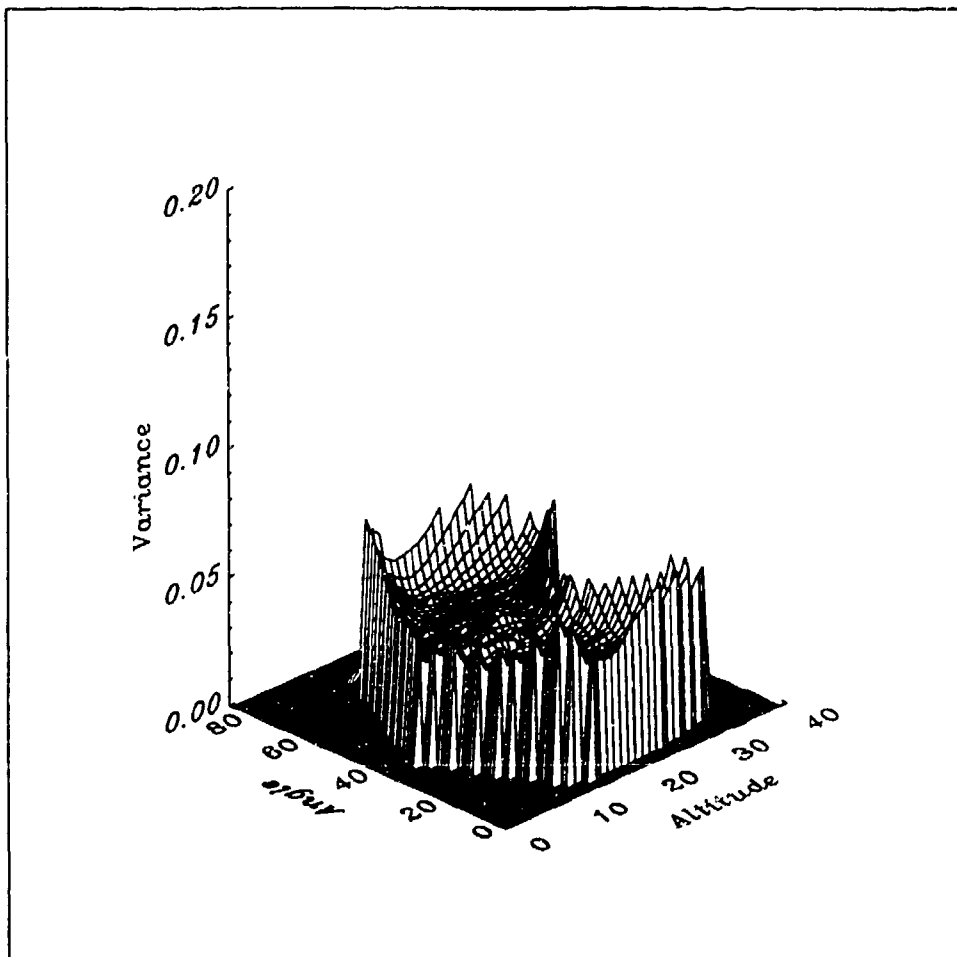
Updated Variances After Subject 173



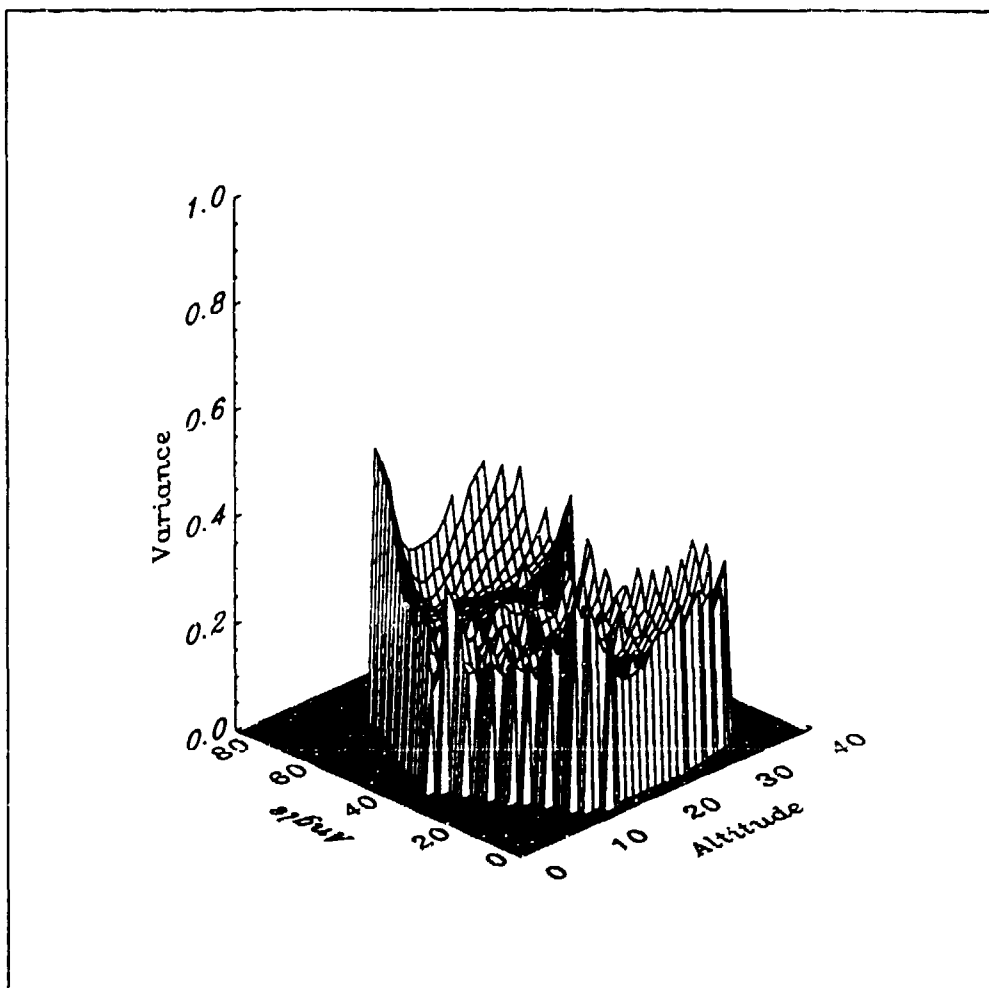
Updated Variances After Subject 176



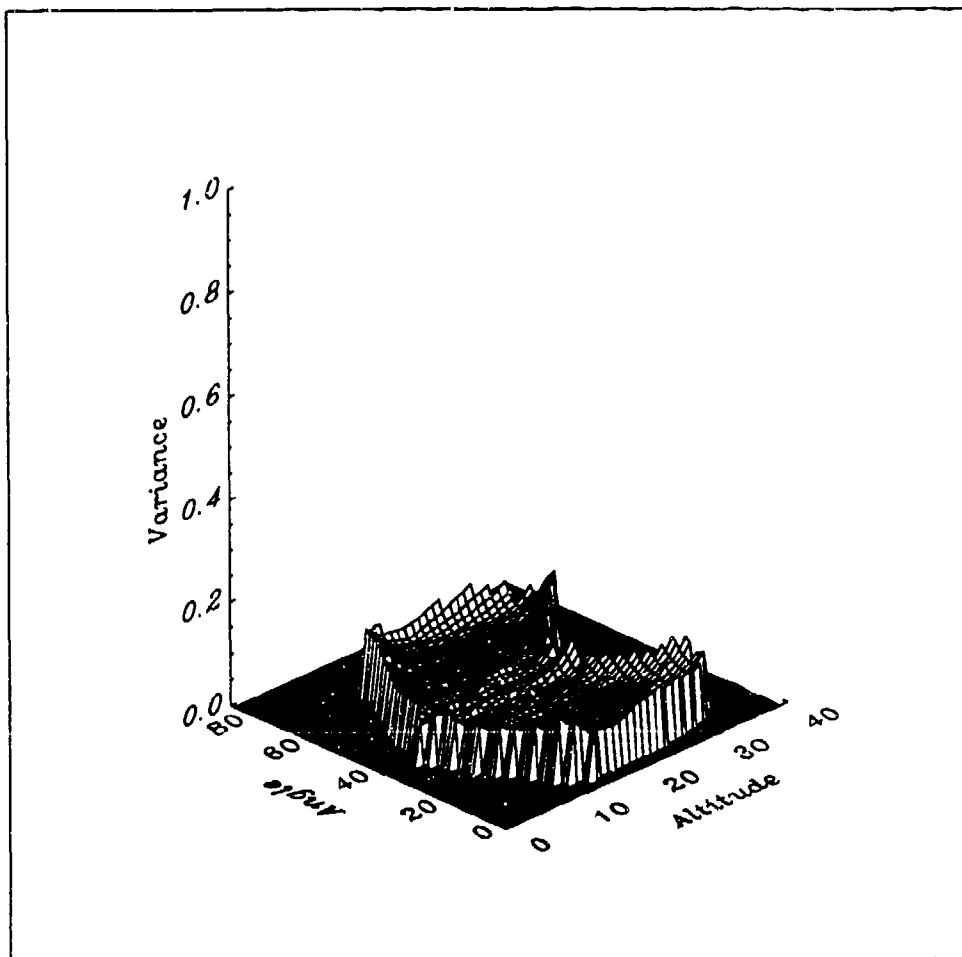
Updated Variances After Subject 183



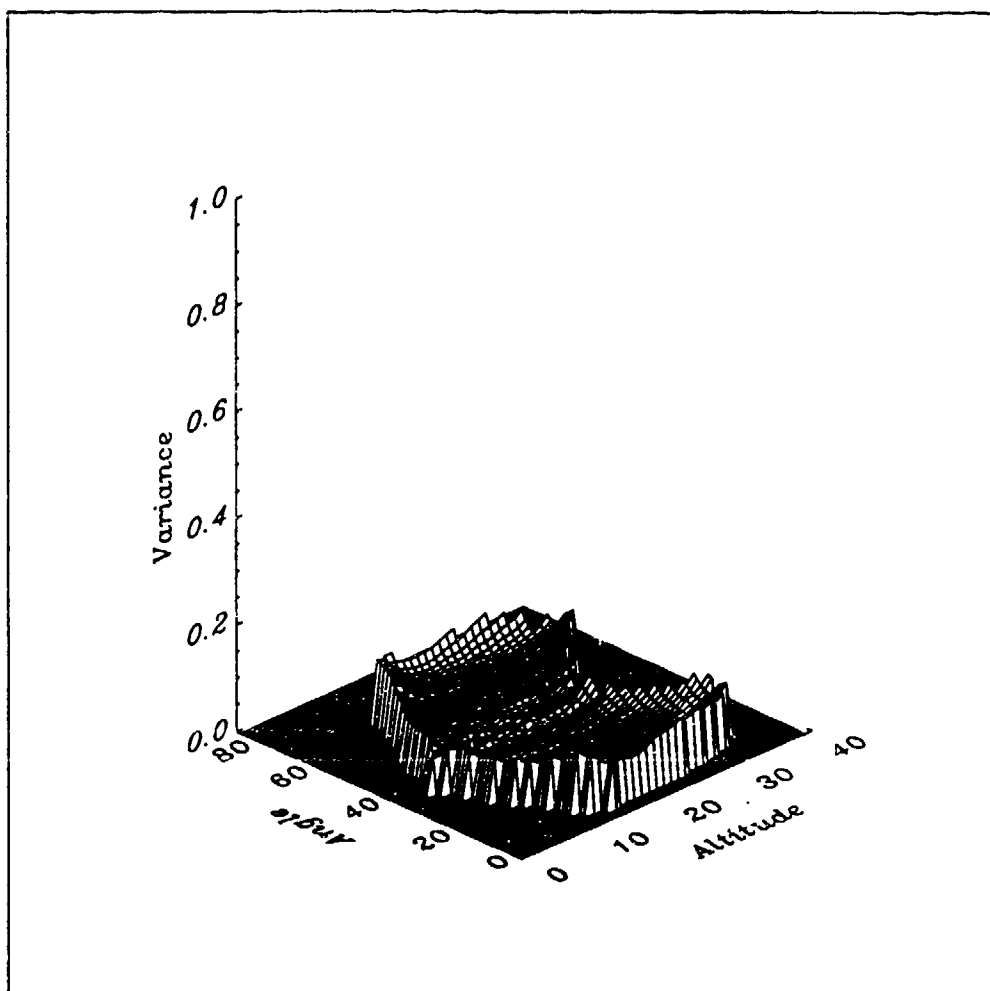
Updated Variances After Subject 185



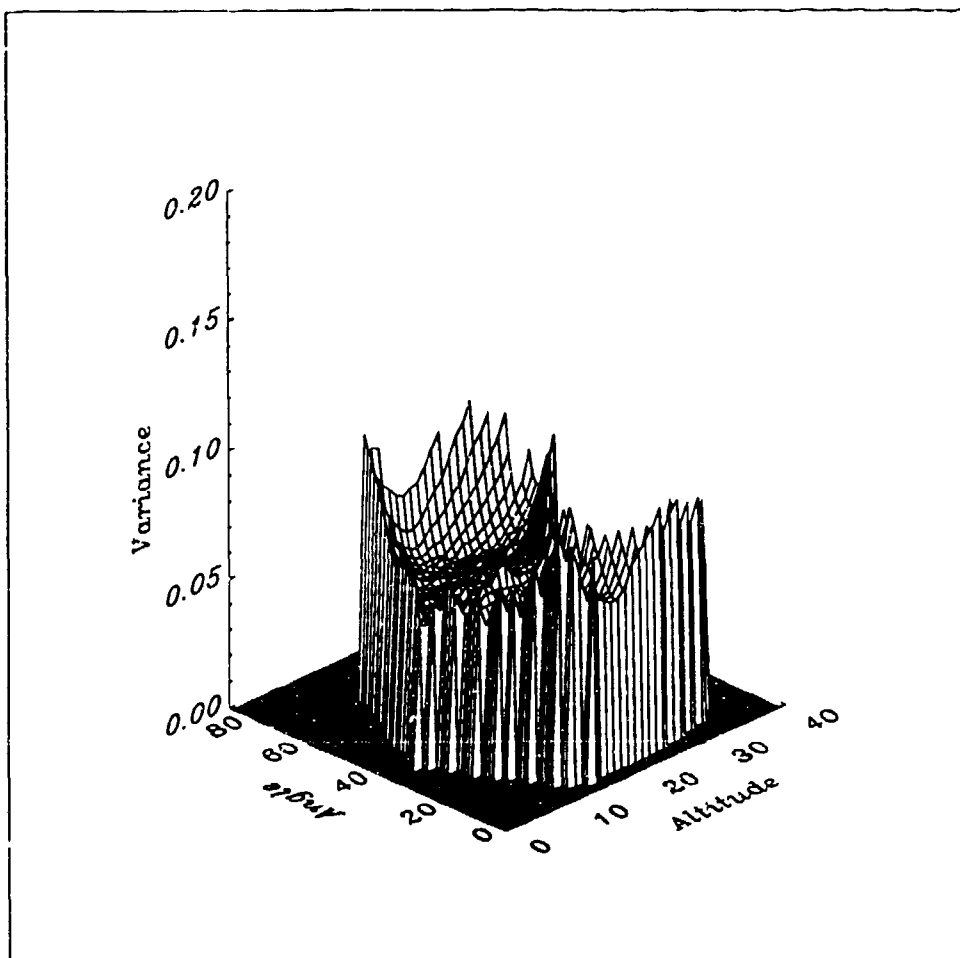
Updated Variances After Subject 112



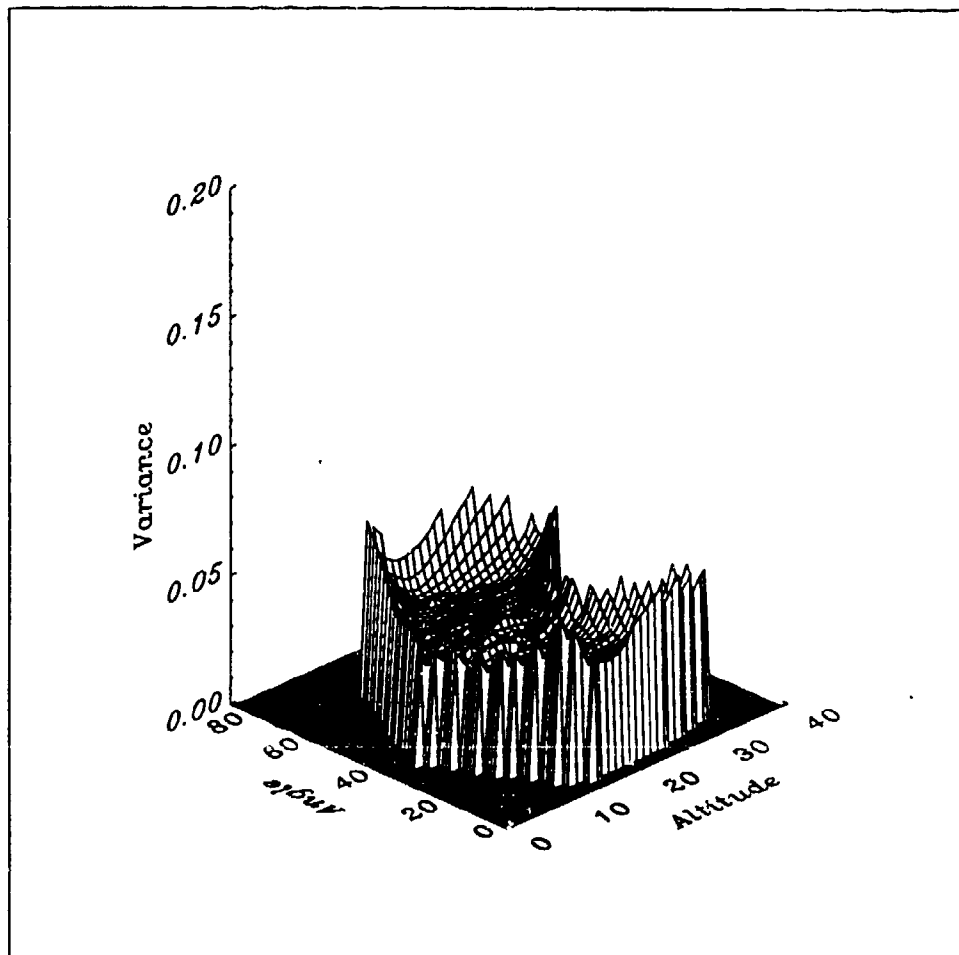
Updated Variances After Subject 141



Updated Variances After Subject 152



Updated Variances After Subject 156



Updated Variances After Subject 199